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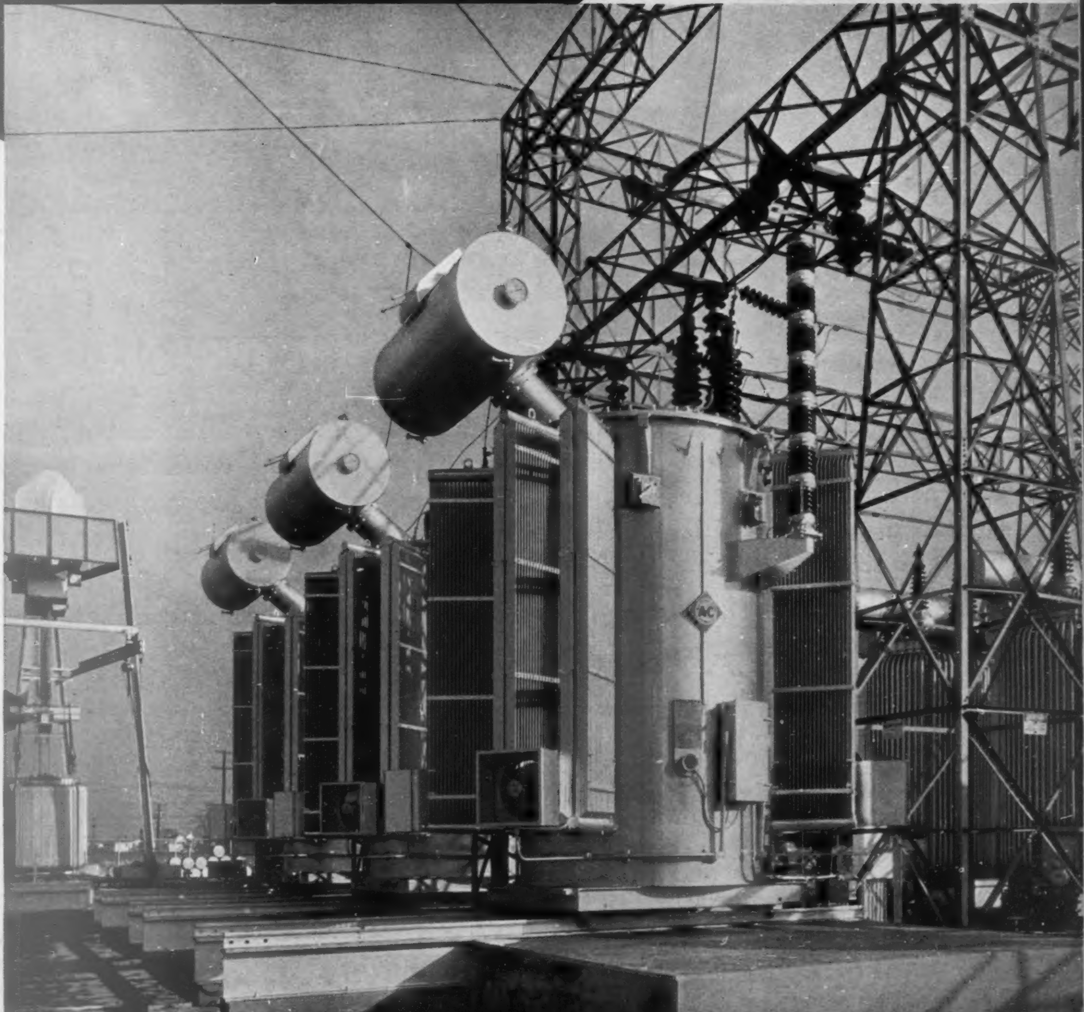
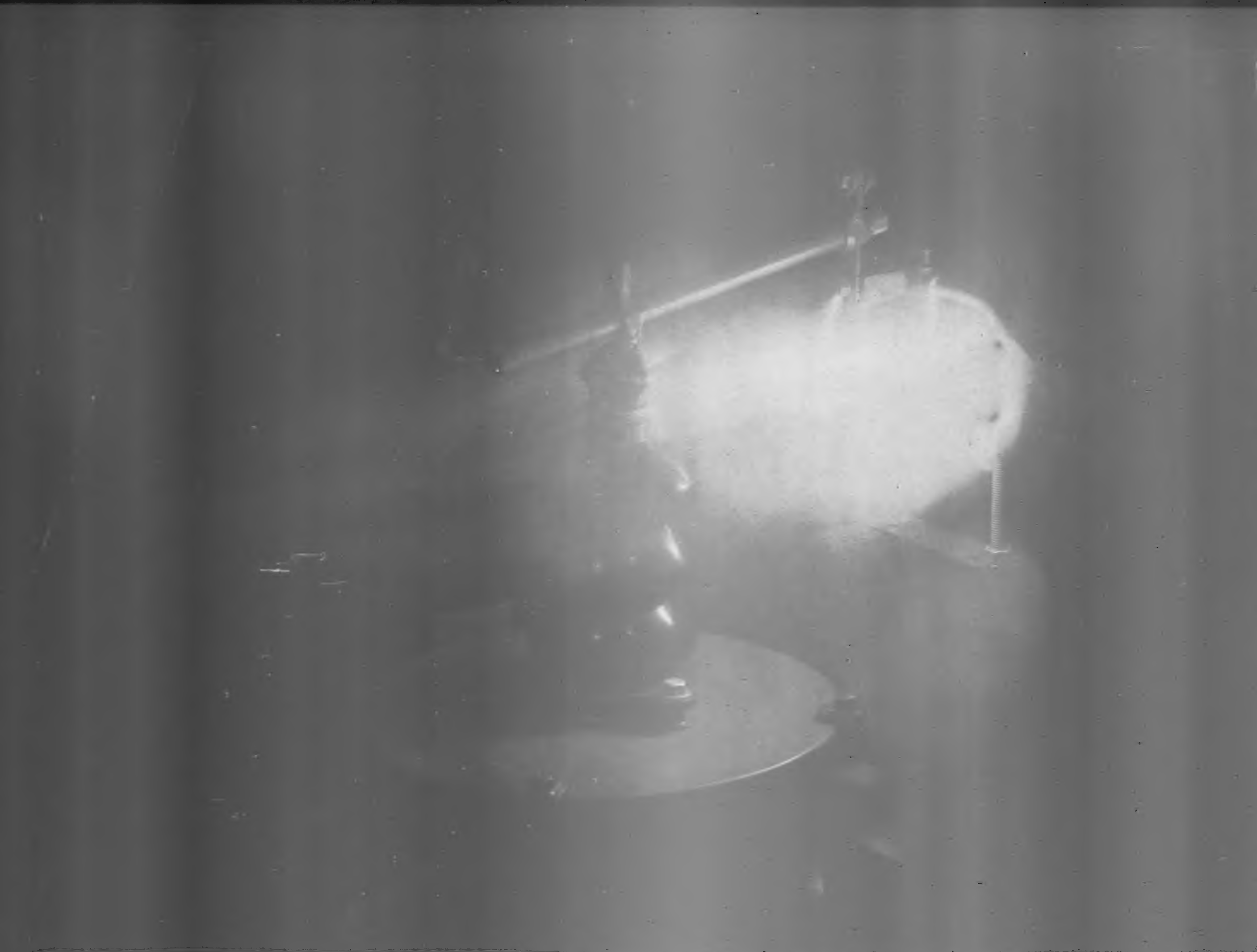
ALLIS-CHALMERS

ELECTRICAL REVIEW

MARCH • 1937





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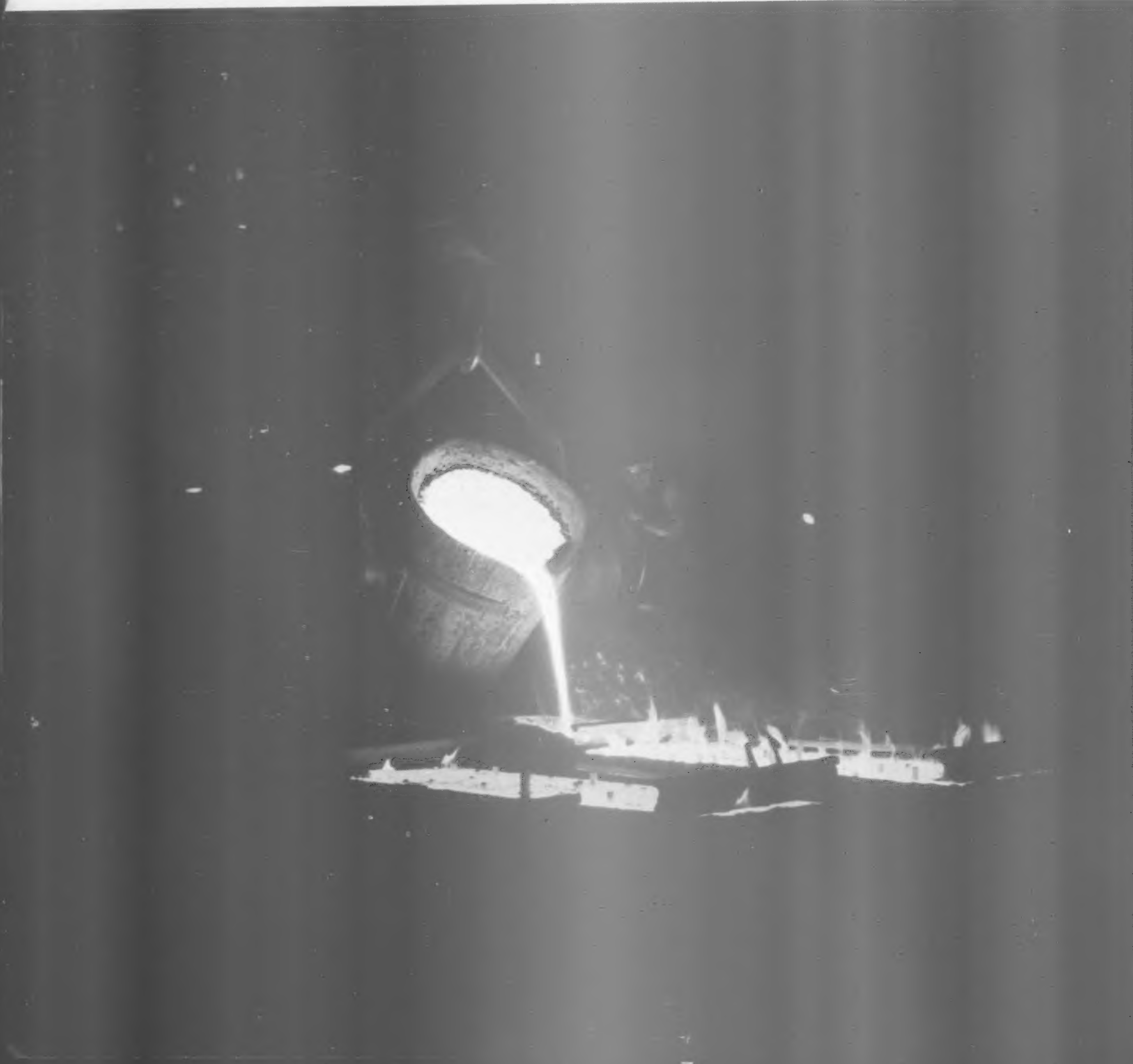
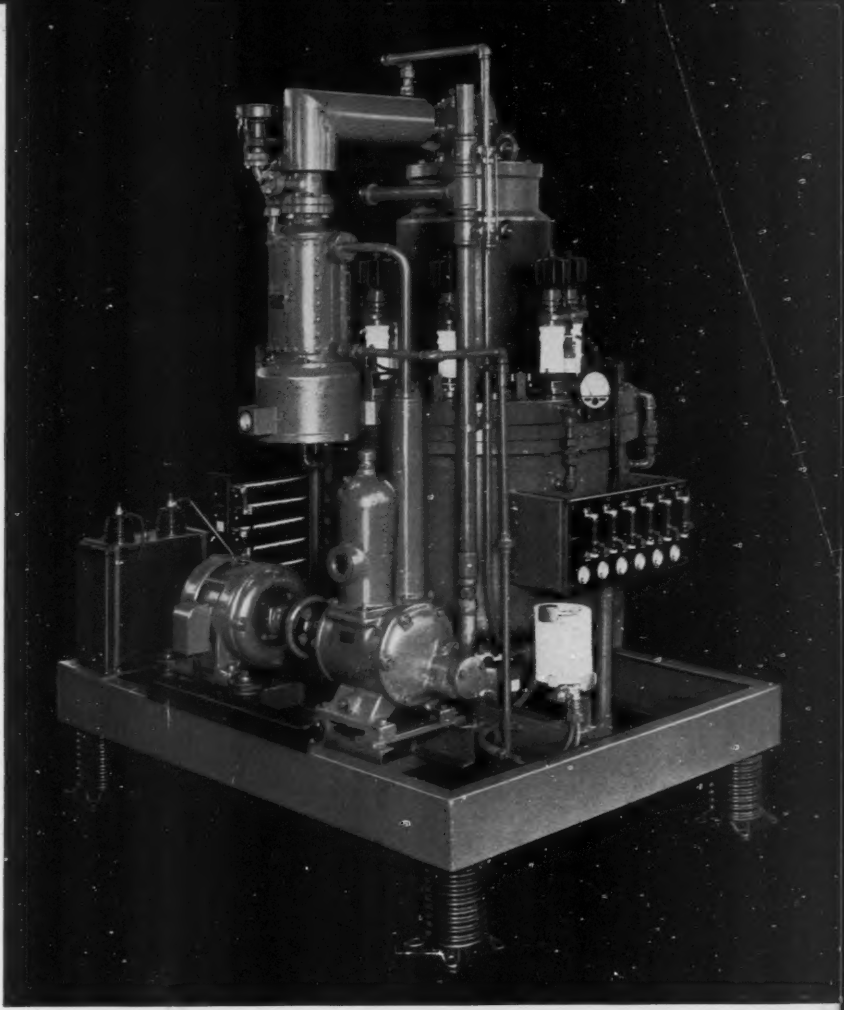
POURING IN THE FOUNDRY





ELECTRONIC SWITCHING IN MERCURY ARC RECTIFIERS

• S. R. Durand

RECTIFIER DIVISION . . . ALLIS-CHALMERS MFG. CO.

By applying suitable potentials to the grids of mercury arc power rectifiers, it is possible to prevent the flow of arc currents between the mercury pool cathode and the anodes of the unit, and thus to effectively open the circuit of the equipment. It is apparent that this blocking action of the grids accomplishes "electronic switching" as contrasted with the "mechanical switching" of a circuit breaker.

The grid elements of steel-tank rectifiers consist of metal or graphite discs mounted just below each anode of the unit within the anode shields. Each disc contains many small openings through which the arc must pass in traversing the space between the mercury pool cathode and any anode. The grids are connected through insulating bushings to an external grid control circuit so that either positive or negative electrical potentials can be applied to them in obtaining controlling action.

Under normal operating conditions of a rectifier, each anode fires and carries arc current during the time it is at highest positive a-c potential in relation to the other anodes. While an anode is firing, the voltage between it and the cathode is equal to the voltage drop in the arc. This voltage drop is dependent to some extent on the design of the rectifier, the temperature of the unit, and the magnitude of the arc current; under normal conditions it is generally within the range of 15 to 30 volts.

The arc current at any instant consists of a flow of electrons from the cathode to an anode through the holes in a grid. Due to the presence of neutral mercury vapor atoms in the space above the cathode, innumerable collisions take place causing the production of an enormous number of electrons for carrying the load current and also of a large number of positive mercury ions. Conventional type grids in the arc path are unable to interrupt the electronic current as long as ionization exists about the grid, for the presence of positive ions prevents a grid from attaining an effective blocking potential to the electronic current flowing through its openings. Grids can thus only obtain control of their associated anodes during intervals when an arc current is not flowing through them, but once they have gained control, they are completely effective in preventing the re-establishment of an arc.

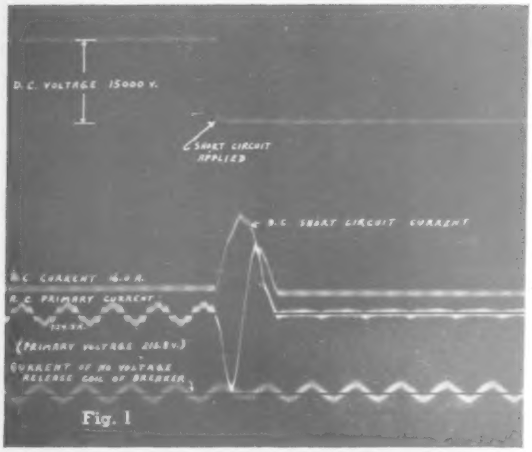


Fig. 1

ing of heavy currents. Electronic switching is used to obtain only temporary interruption of a mercury arc rectifier circuit, and mechanical switching by means of circuit breakers is used for back-up protection and for completely disconnecting the power system. However, in many cases after interruption of a temporary fault by grid control protection, power is automatically restored to the circuit without the a-c line breaker ever having been opened at all.

As an illustration of the rapidity with which power can be interrupted by electronic means in a mercury arc rectifier, an oscillogram is reproduced in Fig. 1 showing complete interruption of a short-circuit in a time of one cycle. As a comparison to this, an oscillogram is shown in Fig. 2 showing interruption of a similar short-circuit by an a-c oil circuit breaker in a total time of 9½ cycles. It is evident from these oscillograph records that electronic switching in a mercury arc rectifier can interrupt short circuits several times faster than mechanical switching, and that, therefore, it is of distinct value in protecting not only the rectifier unit but the rectifier transformer, circuit breaker, and generating units, as well as the equipment in the d-c load circuit.

It would appear that grids in modern mercury arc power rectifiers would be valueless as electronic switches to interrupt an arc current. However, it must be remembered that each anode of a polyphase rectifier carries current for only a fraction of a cycle, so that its grid can always gain control within a very short interval of time. It is actually possible to completely interrupt the circuit within one cycle on the occurrence of overloads or short-circuits by applying a negative blocking potential (in relation to the cathode) to all grids of a mercury arc rectifier unit.

The advantages of electronic switching consist in the simplicity and low cost of the grid control equipment, high speed of operation, and complete absence of contact arcing such as occurs in mechanical switching of heavy currents.

The oscillograph records were made on a 240 kw, 15000 volt rectifier unit for a radio transmitting station shown on page 5. Grid control protection has been used in radio rectifier plants in this country for nearly three years. However, it has also been applied to high power rectifiers in railway service, and one 3000 kw, 650 volt rectifier has been equipped with this high speed electronic system of protection for a period of more than a year at the present time.

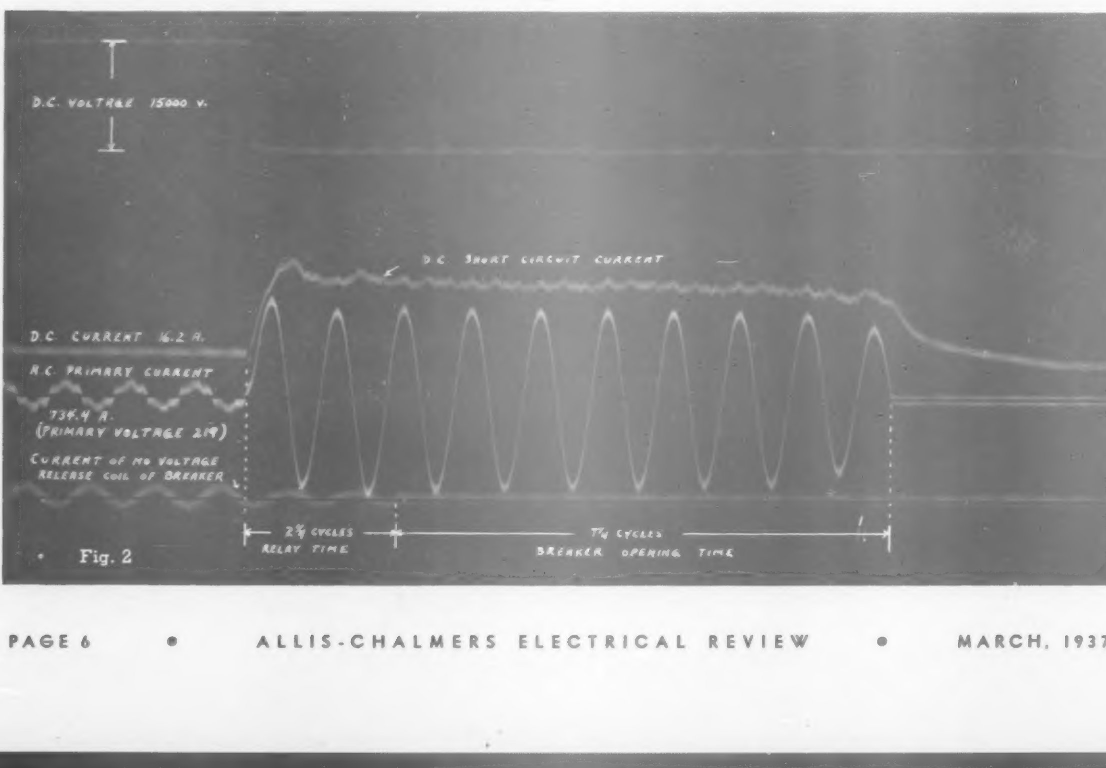


Fig. 2

ENGINEERING FUNDAMENTALS

MOISTURE CONDENSATION IN APPARATUS AND ITS PREVENTION

In machinery or apparatus of any sort, moisture is likely to collect wherever there is an enclosed space. The explanation is simple—the air in the space has undergone ordinary temperature changes, and in going from warm to cool has lost some of its power to hold moisture. The moisture given up by the cool air has not evaporated completely, due to a lack of ventilation in the space, but has collected in the form of water.

This condensation of moisture may be prevented in a number of ways. One obvious method is to keep out all moisture, either by tightly sealing the enclosed space (making certain that the air initially present is dry), or by attaching a dehydrating breather in which the air entering the space passes over a dehydrating medium such as calcium chloride.

Another simple method is to provide enough circulation of air to evaporate the moisture completely. This is done by means of various types of breathers, the size of the space determining what type is to be used. For example, in a small space a single breather is enough, just as a single window serves to ventilate a small room. In larger rooms cross-ventilation is desirable, and likewise in certain larger spaces a double breather provides better circulation of air.

Certain spaces are ventilated still more effectively if forced circulation is provided in some way. An unidirectional breather accomplishes this result, since the air entering the lower breather is heated by means of hot oil and therefore rises and goes out of the upper breather. In a similar manner, the air may be heated by a heater, causing increased circulation in the space.

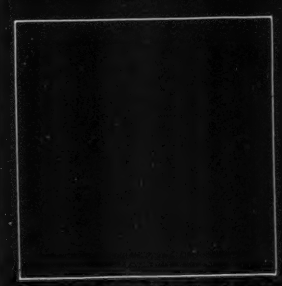


Fig. 1 — Air Tight Enclosure

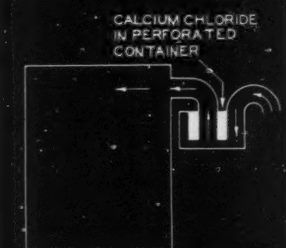


Fig. 2 — Dehydrating Breather

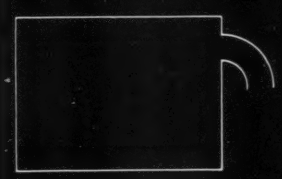


Fig. 3 — Single Breather

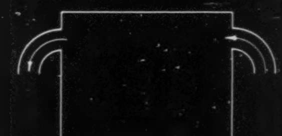


Fig. 4 — Double Breather

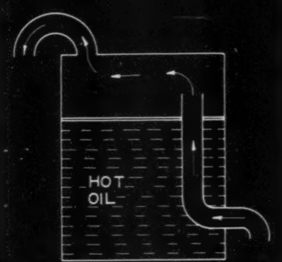


Fig. 5 — Unidirectional Breather

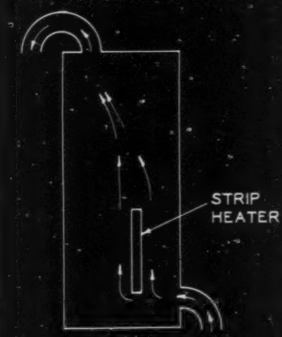


Fig. 6 — Heater

SHORT CIRCUIT RATIO AND STABILITY OF ALTERNATORS

• Sterling Beckwith

ELECTRICAL DEPT. . . . ALLIS-CHALMERS MFG. CO.

Short circuit ratio is a term frequently used in speaking of synchronous machines, yet the significance and limitations of the term are not always well understood. The short circuit ratio for any particular machine will tell the approximate synchronous reactance, but will tell nothing about the transient reactance unless the general speed, size, rating and type of the machine are also known; and even then it will not tell nearly as much as it will about the synchronous reactance. Consequently if a system is such that steady state stability is of no importance, then short circuit ratio is also unimportant, and conversely, if steady state stability is important, then short circuit ratio is also important.

In general turbine generators have a relatively low short circuit ratio and high synchronous reactance making them less stable under steady state conditions than slow speed machines, such as waterwheel generators, which have a relatively high short circuit ratio and low synchronous reactance. Under transient conditions, however, turbine generators with their customary low transient reactances are more stable than are waterwheel generators. Thus we see that stability is determined not only by the value of short circuit ratio but also by the type and speed of the machine as well as the characteristics of the system.

The problem of determining the best short circuit ratio for a machine for a certain application involves a knowledge of the following points:

1. Design factors limiting machine reactance.
2. Normal relations between synchronous and transient reactances.
3. Stability problems in general.
   a. Steady state condition.
   b. Transient condition.

• Design factors limiting machine reactance

The synchronous reactance of a machine is usually defined as $x_d = \frac{OA}{OB}$ in Fig. 1. A clearer picture of why this ratio is a reactance (neglecting resistance) and has the dimensions of a voltage over a current is shown in Fig. 2, where

$$X_d = \frac{OE}{FD} = \frac{\text{open circuit voltage (neglecting saturation)}}{\text{short circuit current at same field current}}$$

The short circuit ratio of a machine is arbitrarily taken as the ratio of the field current required to produce rated voltage at no load to the field current required to circulate rated short circuit current. Referring to Fig. 1 this is

$$\text{short circuit ratio} = \frac{OM}{OA}$$

It is readily seen that this is approximately the reciprocal of the synchronous reactance, X_d, the difference being exactly proportional to the no-load saturation in the machine. Thus short circuit ratio is the reciprocal of a partially saturated synchronous reactance, and the requirement that a machine have a certain short circuit ratio is equivalent to saying that its partially saturated synchronous reactance shall not exceed a certain value. (The term partially saturated is used because, in general, saturation of a reactance is dependent not on the increase in ampere turns due to saturation, but to the slope of the saturation curve, i.e., to the rate of change of flux per ampere turn change.)

From Fig. 1 it can be seen that if a machine is derated to half its normal current rating, its short circuit ratio will be doubled since the distance OA is directly proportional to armature current rating. Similarly if a machine is derated to half its normal voltage rating, the distance OD will be cut in half so that the distance OM and consequently the short circuit ratio will be more than cut in half.

In order to change short circuit ratio without derating a machine, the usual method is to increase the distance OD and decrease the distance OA by decreasing the number of turns in the armature winding. The air gap must be decreased at the same time to avoid overheating the field. Increasing the distance OB directly by changing the length of the air gap would accomplish the same result, but this would result in an increased field current and overheating of the field. (It is assumed that a normal machine is one in which heating is the limiting factor, and not one in which losses must be so low that heating limits are not reached.) The amount by which OD can be increased, and consequently the amount by which OA can be decreased varies with different types of machines, but in general is limited by saturation, core heating, and rotor pole face losses. Thus the amount by which short circuit ratio can be improved by changing machine proportions is limited, and further gain must be obtained largely by derating. The curve of Fig. 3 shows approximately how physical size varies with short circuit ratio for a typical waterwheel generator.

• Normal relation between transient and synchronous reactance

Much has already been published on the normal reactances of synchronous machines, so all that will be attempted here is a somewhat closer correlation between synchronous and transient reactances. This correlation is given in Fig. 4. It should be remembered that each of the lines shown is really a broad band.

Unity power factor machines usually have both a lower transient and synchronous reactance than do eighty per cent power factor machines; the reduction in synchronous is greater than the reduction in transient reactance because the air-gap is usually larger. Synchronous condensers have higher reactances than other machines because their function is chiefly power factor correction, and they have no mechanical load and consequently need no pull-out torque. Motors may differ from the curves of Fig. 4 because of limitations imposed by starting and pull-in conditions, but since motors are usually small compared with the system, their reactances, and consequently their short circuit ratio, are usually unimportant. Furthermore the specifying and testing of pull-out torques will always provide the proper reactances if the equivalent system on which the desired pull-out torque is to be obtained is specified along with the pull-out torque.

The relation between short circuit ratio and transient reactance is not nearly as consistent or fixed as that between short circuit ratio and synchronous reactance. It is too involved to explain here all the design factors that lead to and limit this variation in transient reactance, but the principal factors are the machine speed and the ratio of air-gap length to pole pitch. In two pole machines, the transient reactance may be only one-tenth of the synchronous reactance, and in slow speed alternators, the transient reactance may be over one-third of the synchronous reactance even for normal machines. Since the most desirable value for transient reactance is one which is low enough to provide stability, but high enough to limit circuit breaker duty, the usual variations from normal design for turbine generators is to make the transient reactance as high as possible; and for slow speed waterwheel generators to make the transient reactance as low as possible. However, this is not a hard and fast rule, and such conditions as voltage dip, power factor, overloads, load swings, and system connections may make other values desirable.

• Stability

A fundamental fact regarding all alternating current systems is that there is a definite maximum amount of power that can be transmitted at a given voltage through any circuit containing reactance. An analogous situation occurs in a direct current circuit as a result of resistance in the circuit. However, since ordinary wires, transmission lines, and electric machines have from ten to fifty times more reactance than resistance, the maximum power, or stability limit, becomes much more important in a-c circuits than in d-c circuits. The following discussion will treat steady state limits separately from transient limits, since synchronous machines have different effective reactances under the two conditions.

Steady state power limit. If an alternating voltage is applied to each end of a pure reactance, and power is made to flow through the reactance in the usual manner by slowly displacing one vector voltage with respect to the other, the power-displacement relation will be as shown in Fig. 5, and a maximum power equal to:

$$P_{max} = \frac{\text{sending end voltage x receiving end voltage*}}{\text{reactance}}$$

will occur when the displacement equals ninety degrees.

The significance of such a maximum power becomes apparent for the ordinary power system when it is remembered that a synchronous machine can be approximately represented by a simple reactance. Consider, for a moment, an average synchronous motor. The maximum continous power this motor will deliver under five different conditions, neglecting saturation and losses, will be as shown in Table I. These values are calculated from the last equation after determining graphically the internal voltages.

Two things will be noted in Table I. First, that maximum power when the power source is an infinite bus is always greater than the maximum power when the power source is a duplicate ma-

*All quantities are magnitudes and not vectors.

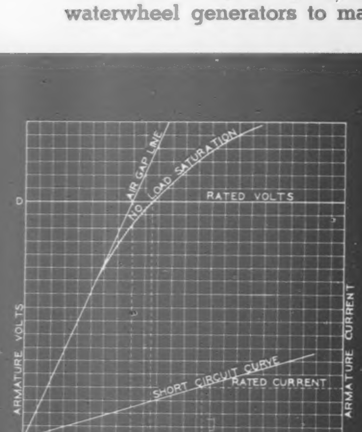


Fig. 1

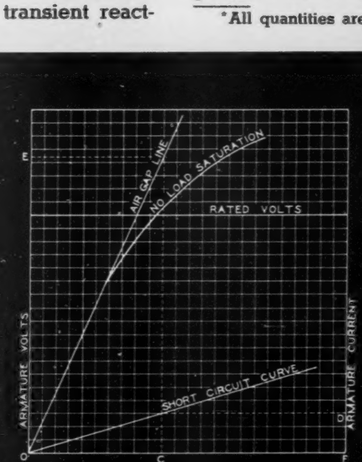


Fig. 2

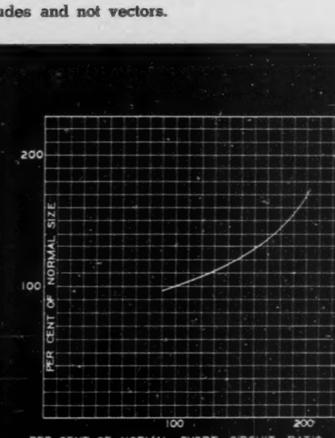


Fig. 3

chine; and second, that maximum power is affected greatly by system excitations. (It should be recalled that steady loads only are being considered now, and that saturation and losses are being neglected.)

In practice, where a motor or generator is connected to a network, conditions differ from case A of Table I only by the small amount of the transformer reactance in the machine terminals. The only condition for which this is not strictly true would be where the machine capacity was more than ten or twenty per cent of the system connected load, or where the machine was at the end of a transmission line. Consequently normal machines are designed to have satisfactory steady state pull-out torques and pull-in torques for approximately infinite system conditions. The only exception to this is that waterwheel generators are normally designed to allow for a reasonable amount of line reactance. Thus, if a machine is to be operated under other than approximately infinite bus conditions, it becomes necessary to specify special machines if "infinite bus torques" are desired.

Just how to describe the machine characteristics to be sure of obtaining the desired torques under special conditions is a matter that has not yet been standardized. Perhaps the most accurate method, where saturation is important, is that of determining equivalent reactance of the system and of the machine.* A second method often used in calculating board studies, is that of driving point and transfer impedances.** A third method is to simplify the system until it becomes a single machine with series impedance, and then decide by using the equation on page 9 (or a modification of it taking into account the resistance) what synchronous reactance a machine can have in order to deliver the desired amount of power. And it is due to the close relation between synchronous reactance and short circuit ratio that short circuit ratio is often assumed to be a measure of the inherent stability of a machine. Because of the difficulty of making an accurate solution, the effect of saturation is sometimes neglected entirely as in the second and third methods, and is assumed to provide a satisfactory margin of safety, so that the system as calculated without saturation need be just stable and no more.

*Crary, Schildneck & March—Equivalent Reactance of Synchronous Machines. Elec. Eng'r. Jan. '34; H. B. Dwight—Adjusted Synchronous Reactance and Its Relation to Stability. G. E. Rev. Dec. '32, p. 609; S. Beckwith—Steady State Solution of Saturated Circuits. Elec. Eng'r. July '35, p. 728; Chas. Kingsley—Saturated Synchronous Reactance. Elec. Eng'r. March '35, p. 300.

**E. Clarke & R. G. Lorraine—Power Limits of Synchronous Machines. AIEE Trans. Nov. '33, p .780; S. B. Crary—Steady State Stability Characteristics of Composite Systems. Elec. Eng'r. Nov. '33, p. 787.

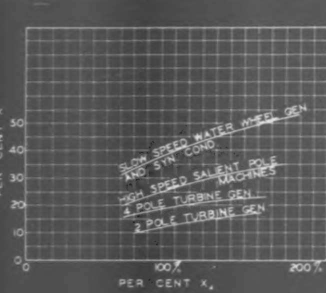


Fig. 4

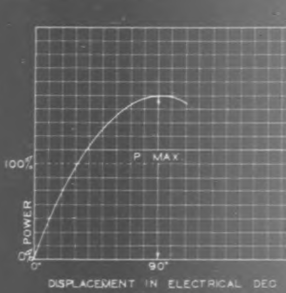


Fig. 5

TABLE I

MAXIMUM "PULL-OUT" POWER OF TYPICAL SYNCHRONOUS MOTORS
(In percent of full load rating—saturation and resistance neglected)

	Typical .8 PF Machine	Typical 1.0 PF Machine
A. Power supplied from an infinite bus*		
1. Motor operating with rated field current	178%	167%
2. Motor operating with no-load field current	100%	133%
B. Power supplied from a duplicate machine		
1. Both machines operating with rated field current	156%	103%
2. Both machines operating with no-load field current	50%	67%
3. Voltage regulator on generator and rated field current on motor	88%	127%

*An infinite bus can be defined as a bus whose voltage does not vary with either suddenly applied or slowly applied load. (A generator with voltage regulator is not an infinite bus because its voltage varies with suddenly applied loads.)

The above values were calculated from the last equation, and therefore saturation and losses were neglected.

The typical synchronous machine was assumed to have the following characteristics:

80% PF machine, synchronous reactance = 100%
100% PF machine, synchronous reactance = 75%

Transient power limit. Transient conditions are not quite as simple to analyze or generalize as steady state conditions. In transient stability problems, inertia, or WR^2 of a machine or the system is important, whereas in steady state problems it is of almost no importance. Likewise speed of switching, speed of excitation, and rate of change of load are important, and transient reactance instead of synchronous reactance controls the behavior of a machine. Thus the question of whether a transient reactance other than normal is needed really requires an individual stability study in most cases.

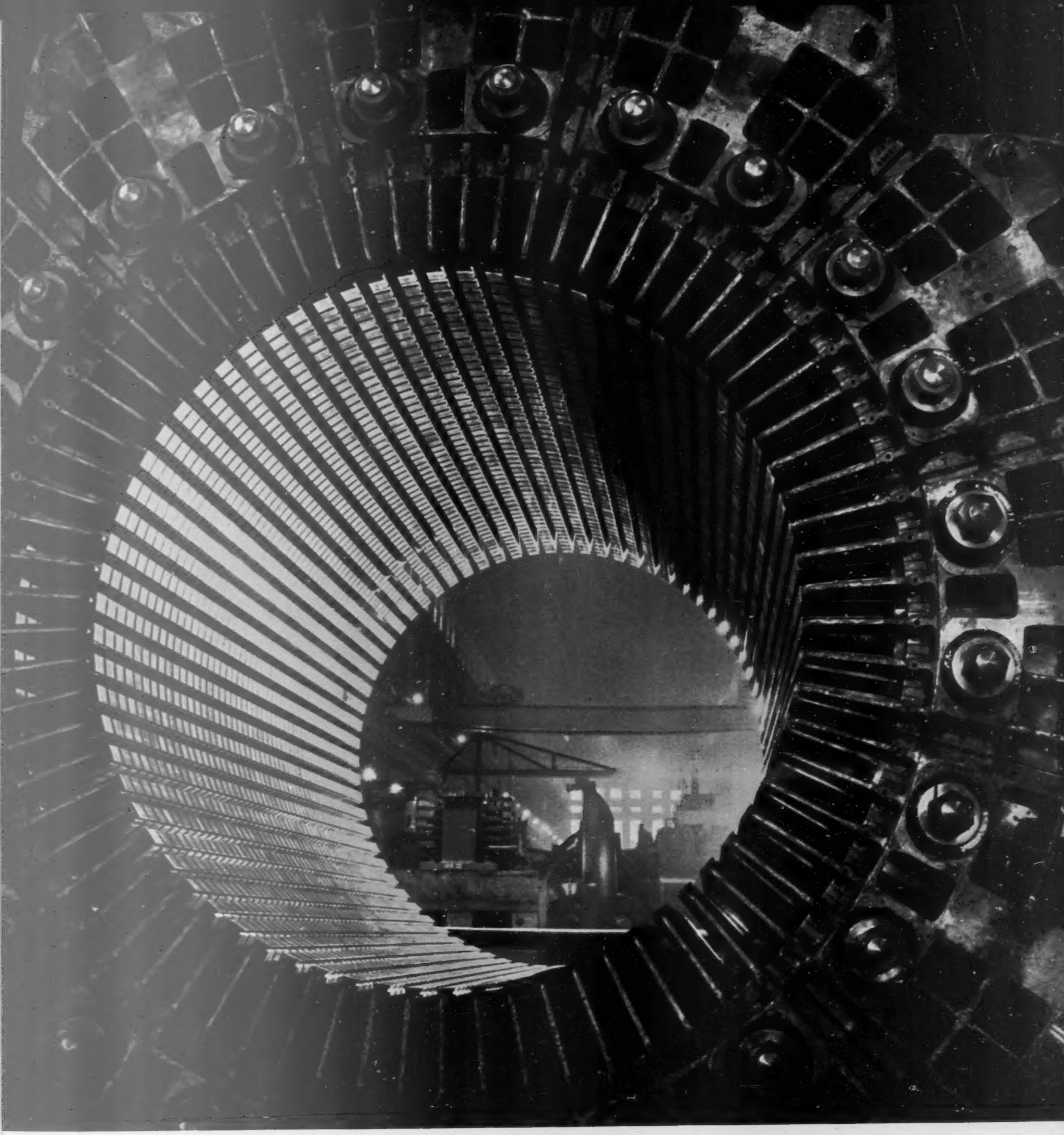
Usually, however, certain types of machines, such as two pole turbine generators, have too low a value of transient reactance, since they require either very high rupturing capacity breakers, or current limiting reactors. Other types of machines, such as slow speed generators have high transient reactances, and often when the machine is to operate at the end of a transmission line, the obtaining of low transient reactance may be the limiting factor in the design of the machine, and may make the physical size of the machine greater than normal.

In general the necessity for a given short circuit ratio can be determined only from a stability study of the system on which the machine is to operate.

Short circuit ratio is closely related to synchronous reactance, and may be used interchangeably in steady state calculations.

Short circuit ratio is not very closely related to transient reactance, even for a given type of machine, and over the range of all synchronous machines the relation may vary very widely.

Short circuit ratios somewhat higher than normal can be obtained without great increase in machine size, but further increase in short circuit ratio must be obtained largely by derating the machine.



TURBO-GENERATOR STATOR

INERT GAS PROTECTION FOR TRANSFORMERS

• L. H. Hill, Engineer-in-charge
TRANSFORMER DIVISION . . . ALLIS-CHALMERS MFG. CO.

Theoretically there is no question but that inert gas protection for power transformers is a good thing. Moisture and oxygen are the two enemies of transformer oil, and the isolation of these two provides ideal operating conditions for transformer oil. In addition, a cushion of inert gas above the oil and the elimination of a head of oil above the cover minimizes the danger of fire and severe external mechanical damage in case of trouble inside the transformer case.

The cost of power transformers provided with inert gas protection is the same as those provided with expansion tanks or conservators; hence with the acknowledged advantages listed, whether or not to specify inert gas protection must hinge on whether or not it is more trouble or more costly to operate.

For minimum maintenance expense an ideal inert gas system for a transformer should not require the periodic replenishment of any material and should operate without mechanical devices requiring inspection, adjustment or replacement after a period of operation. Furthermore, the ideal system should operate at practically atmospheric pressure to avoid possibility of gas leakage.

An inert gas system has been developed and tested in service which does operate without periodic replenishment of material, without mechanical devices, and with a pressure deviation from atmospheric varying from a maximum of only one-half to one pound per square inch depending on the size of the transformer.

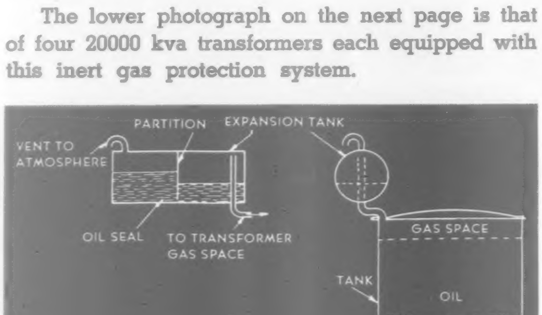
Fundamentally, this inert gas system consists of an expansion tank divided into two parts of equal volume with an opening in the bottom of the partition to form a large oil seal. The top of one section connects to the gas space in the main transformer case, and the top of the other opens to the atmosphere as shown in the schematic diagram on this page.

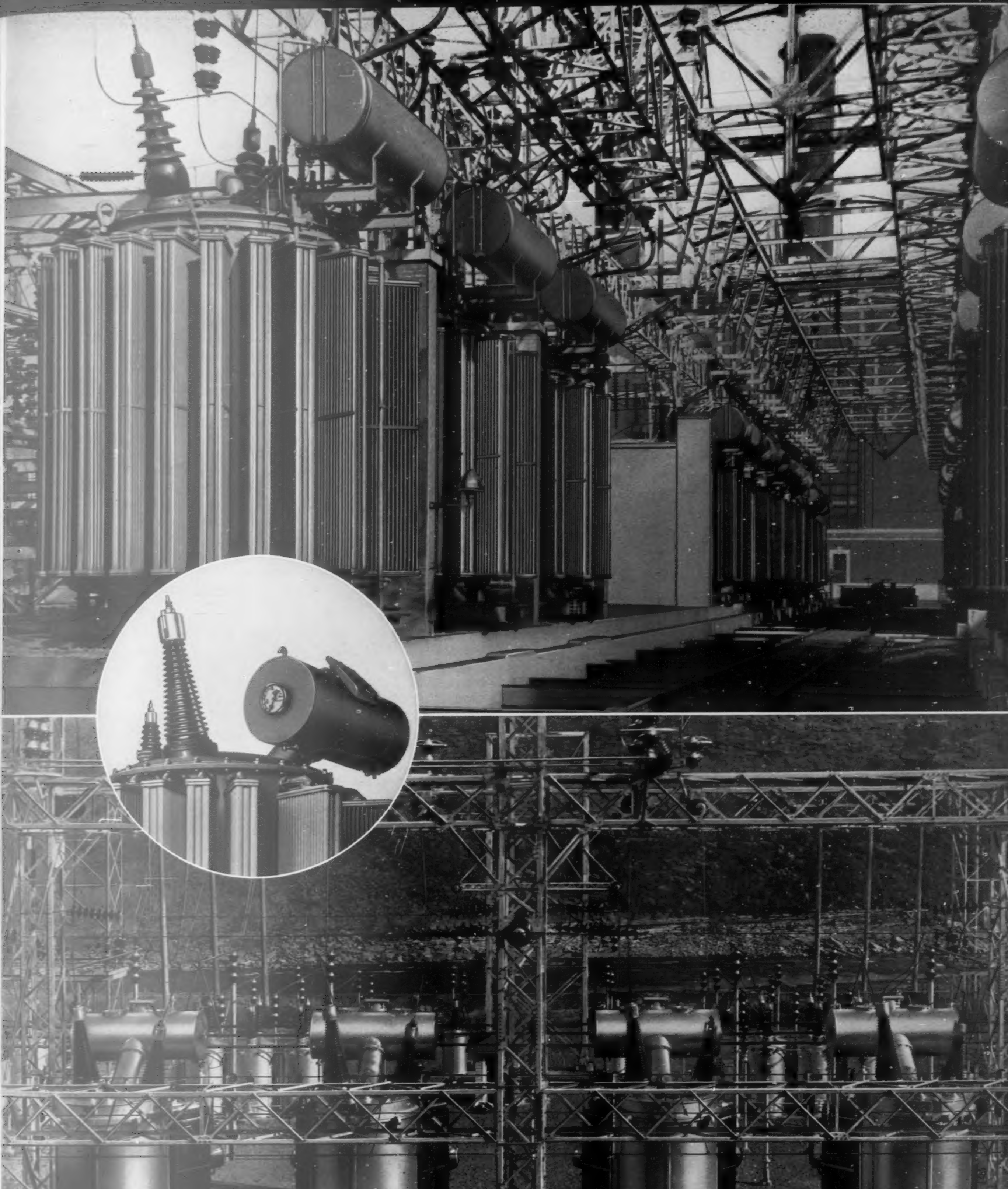
The operation of the system is very simple. When the oil in the main transformer tank expands due to an increase in temperature, the pressure in the gas space above the oil increases slightly which lowers the oil level in one-half of the oil-seal tank and elevates it in the other half as indicated. The additional volume provided in addition to the volume of gas in the main tank by this movement of oil in the seal permits considerable change in oil level in the main tank with but slight increase in pressure in the gas space. Upon cooling down of the oil the reverse action takes place so that the liquid seal in the expansion tank effectively isolates the gas above the oil in the main tank from the atmosphere, under all ordinary conditions of operation.

The expansion tank is usually supported by the abnormal-pressure relief pipe as shown in the circle on the opposite page. An opening in the relief pipe at the top provides the connection between the transformer gas space and one side of the divided expansion tank. This avoids the use of separate piping.

The top photograph at the right shows eighteen 15000 kva transformers placed in service simply with air (20.7% oxygen content) above the oil in the main tank. After two years of service, with no maintenance or inspection of the inert gas system, an oxygen content in the gas space of only 2.0% was found. This is due to the oxygen in the gas space combining with the oil itself. The amount of sludging of the oil during this period is, of course, negligible, because the supply of oxygen is limited. Obviously the air above the oil may be removed initially by blowing out with nitrogen if desired, and sufficient nitrogen gas is supplied with the equipment for this purpose along with an oxygen analyzer for each installation. Once having blown out the oxygen in the gas space and that which comes out of the oil, the system will operate indefinitely without attention.

The lower photograph on the next page is that of four 20000 kva transformers each equipped with this inert gas protection system.





PATENT FALLACIES

• Leo Teplow,

PATENT ATTORNEY, ALLIS-CHALMERS MFG. CO.

This article is not intended to be a "debunking" of our patent system. It is merely an attempt to point out a few of the erroneous assumptions which have gained currency to the detriment of many who are unfamiliar with the operation of our American patent system and who cannot afford the time to investigate for themselves. Needless to say, a brief resume of this nature cannot replace expert patent advice, although it may be an aid in obtaining and digesting opinions from competent patent counsel.

Perhaps the most common of all fallacies concerning inventions is the hoary myth that if a man invent an improved mousetrap, the world will beat a path to his door. It is doubtful if this ever was a true statement of fact. Think of the disheartening difficulties encountered by such noted inventors as Fulton and his steamboat, Morse and his telegraph, Bell and his telephone, the Wrights and their aeroplane—despite the fact that their inventions were to change the course of world history. In every case, the inventor had to overcome the inertia and apathy of a stubborn world before being permitted to utilize his invention in a commercial sense. Certainly the world did not beat a path to his door to offer untold wealth in return for the invention. In too many cases, recognition does not come until the inventor is dead, and his patents perhaps expired as well, as exemplified by Fritts and moving pictures with sound accompaniment.

It should be noted that by far the greater number of inventions are not basic or "pioneer" inventions. They are far more likely to be improvements on existing apparatus or methods. Such an invention must compete with those already in the field. If the invention ever receives adequate consideration with a view to commercial exploitation, the inventor must show more than the simple fact that his mousetrap is an improvement. He must also show

1. That the improvement warrants replacement of existing mousetraps by the new one;
2. That the improvement warrants replacement of dies and machines used in the manufacture of present mousetraps by the new machines which will be required to manufacture the new mousetraps;
3. That manufacture of the new mousetraps will not be substantially more expensive;
4. That manufacture, use and sale of the new mousetrap will not infringe patents belonging to others; and
5. That the new mousetrap can be protected by patents sufficiently broad to prevent possible competitors from making substantially equivalent mousetraps.

Thus it is seen that merit—in this case, ease of operation and efficiency in catching mice—is not the only consideration involved in considering a new invention. In fact, modern advertising and high pressure salesmanship have in many cases relegated merit to a secondary place. From the promoter's point of view, such things as "sales appeal," "eye appeal," "talking points," etc.—features which are only too often removed from true merit—are far more important than the efficiency of operation of the device sold. If the Kachamouse Corporation of America has, by dint of ballyhoo through billboards, women's magazines and farm publications, sold eight million of their new 1937 streamlined mousetraps, the directors are not likely to approve the expenditure of more funds for additional machinery to make an improved mousetrap. Advertising, not merit, is relied upon in this case to sell the manufacturer's output. An improved mousetrap may receive consideration if it costs no more to make, but it is perhaps closer to the truth to say that inventors will beat a path to the reception room of the Kachamouse Corporation, than vice versa. This is admittedly an extreme instance, used to exemplify an existing condition of affairs.

Another fallacy, closely allied to the first, is that the easiest road to wealth for an inventor lies in acquiring a patent. A patent does not of itself bring wealth, nor sales of a product, nor even assured protection. At the present time the United States Patent Office issues between 700 and 800 patents weekly. We are not making men wealthy at that rate. In the past ten years, over 450,000 patents have been granted, during a period which has not been noted for the number of million dollar incomes.

While figures are hard to obtain, it may be said with little fear of opposition that a large proportion of patents issued are of little or no commercial value. Perhaps as many as one-half of them do not repay the expenditure involved in obtaining them. A considerable number of patents are known as "paper patents"—drawn to features which may or may not be useful but which for lack of merit or opportunity are never utilized commercially. Some of these may be difficult to exploit because of lack of market or because the effective demand is already supplied by competing articles or processes which serve the purpose; or there may be no entrepreneur willing to undertake the manufacture and sale of the patented article; or the inventor and manufacturer cannot agree on an equitable distribution of the proceeds.

Another obstacle in the way of exploiting a patented mousetrap is that patent protection may suddenly terminate. A competitor may be able to prove that a mousetrap embodying the features claimed in the patent was in public use more than two years before the inventor filed his patent application; or that some person other than the applicant was the first inventor; or that the alleged invention is merely the result of mechanical skill applied to previously known mousetraps, and does not rise to the dignity of invention, despite the fact that the Patent Office

permitted the patent to issue. These, and many other defenses may be set up by an infringing competitor, to limit or destroy the protection afforded by the patent. It might be well, in order to emphasize the fact that patent protection may be destroyed, to emulate the policy of the French Patent Office in stating that patents are granted "without guarantee of the government." In the interest of fairness, it should be stated that United States patents are legally presumed to be valid until proved to be invalid. Even if the patent is valid, it may be found that a competitor may be able to make a mousetrap which is just as good by changing the construction in such a way as to avoid the claims of the patent. The above is sufficient to point out that a patent does not assure the inventor or assignee an easy road to wealth, sales or even certainty of protection.

A third fallacy, recurring again and again, is the notion that a patent grants its owner the right to manufacture the patented article. This is very far from the facts. A patent for a mousetrap gives the owner the right to use the courts to prevent others from making, using or selling mousetraps embodying the features claimed in his patent. But others may hold patents covering certain features of the patented mousetrap, and they have a similar right to prevent any one else, including the inventor of the improved mousetrap, from utilizing these patented features during the life of these patents. For example, John Doe gets a patent on an improved mousetrap which includes, among other things, a special spring. Richard Roe holds a patent covering this special spring. John Doe cannot make, use or sell his patented mousetrap without infringing Richard Roe's spring patent. John Doe's patent does not give him the right to manufacture his patented mousetrap, unless he gets a license from Richard Roe. In fact, it would be highly desirable for John Doe (or his attorney) to make an infringement search —i.e., to consider the claims of all unexpired patents relating to mousetraps and parts thereof—to ascertain whether he is free to manufacture, use or sell his patented mousetrap.

Another fallacy frequently encountered is the idea that the marking "Pat. Pending" denotes patent protection. If such marking is applied in good faith, it indicates that the manufacturer or his licensor or assignor has filed an application for a patent to cover one or more features of the articles so marked. It denotes no present protection at all. It simply serves to notify the public that at some future date a patent *may* issue which may give the owner the right to prevent the public from further manufacture, use or sale of certain features of the article so marked. It is true that after a patent issues, the owner will have a right to proceed against those who are still using the patented device. And if these users are customers of a responsible manufacturer, the manufacturer may undertake to reimburse the patent owner for any damage he may suffer by reason of continued use of the patented article by the manufacturer's customers.

A final word about extent of patent protection. Just because a mousetrap is patented, the patent owner usually does not have a monopoly on all features of the patented mousetrap. His monopoly extends only to the features or combinations of features *claimed* in the patent, and their equivalents. It may be that the features claimed are unimportant and may be omitted, or may be replaced by other (non-equivalent) features. Therefore the extent of patent protection is not indicated at all by the usual patent marking, and the claims of the patents themselves must be consulted. These claims in turn may not be self-explanatory, and it may be necessary to consult the Patent Office file of the patent, and construe the claims in view of the art cited therein and arguments utilized to obtain allowance of the claims. The mere fact that a mousetrap is made under a patent is no indication how far the public is free to go in utilizing features of the patented construction. The patent claims, at least, must be consulted.

It is only fair to point out that fallacies concerning patents are not limited to the layman. Among the most assiduously cultivated fallacies current among patent attorneys as well as engineers, examiners, and executives is the notion that our patent system is directly responsible for our high standard of living and the high level of our industrial civilization with its accompanying mechanical marvels and peaks of prosperity. For example, an eminent patent attorney was quoted as follows in the Patent Office Journal a few years ago: "Our patent system has been *the* primary factor in making America foremost among the nations in agriculture, inventing and manufacturing. While there are other factors, the patent system is by far the most potent one." To those engaged in patent practice this is a flattering idea, sown in a field fertilized by the will to believe. Needless to say, it cannot stand the test of critical examination. Regarded with any degree of healthy skepticism, the idea is quite preposterous, even though it is entertained by many who ought to know better. Isn't it likely that a temperate climate and tremendous natural resources have something to do with our high standard of living? Isn't it a slight on the initiative and ability of our people, our well known traits of mechanical skill, Yankee ingenuity, high standard of literacy, etc., to regard our industrial advances as being due directly to this specific patent system? Perhaps a better way to indicate the fundamental error of this broadly accepted idea is to consider whether the adoption of our patent system in, let us say, Siam, would result in an American standard of living and a rate of industrial progress equivalent to ours. Moreover, if our patent system is responsible for our peaks of prosperity, must it not also take the responsibility for the depths of depression we periodically experience?

The writer realizes his rashness in questioning so commonly accepted an "axiom" in our patent system, but trusts that the system has sufficient inherent worth to sustain a critical, unbiased examination, and does not need to be buttressed by ridiculous claims.

Probably every inventor and patent practitioner has his own pet list of patent fallacies. The few listed above certainly do not constitute an exhaustive list, and the individual fallacies are treated in summary fashion only. It is hoped, however, that this summary may save engineers, inventors, and manufacturers many valuable hours of unnecessary discussion due to false ideas about certain features of our patent system, and perhaps lead to a more realistic outlook on patents and their place in our industrial system.

HOT STRIP MILL MOTOR ROOM

VARIABLE VOLTAGE VS. MOTOR FIELD SPEED CONTROL FOR D-C DRIVES

• J. F. Sellers and T. B. Montgomery
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Generally d-c motors are designed in all sizes with a 2:1 speed range by shunt field control or a greater range in specific cases.

The question then arises as to why with a given 2:1 speed range motor, where variable voltage control can be used, it is not always possible, within good practice, to use a motor with twice the base speed of the 2:1 motor with variable voltage control and operate with full motor field current, since in general the higher the speed the lower the motor price.

Almost universally speed is controlled by either of two methods or a combination of these two:

1. Shunt field weakening.
2. Variable voltage or Ward-Leonard.

When the first method is used, the motor torque is decreased at speeds above base (full field) speed inversely in proportion to speed increase. Then with a 2:1 motor speed range by field control, the available torque is half at full speed what it is at half speed (see curve XYZ, Fig. 3), that is, at maximum armature current.

With the second method in which the generator voltage is varied to obtain motor speed control, the motor torque corresponding to full load current (with fixed motor field) is constant for any speed from zero to maximum speed corresponding to full generator voltage (see curve V, W, Fig. 3).

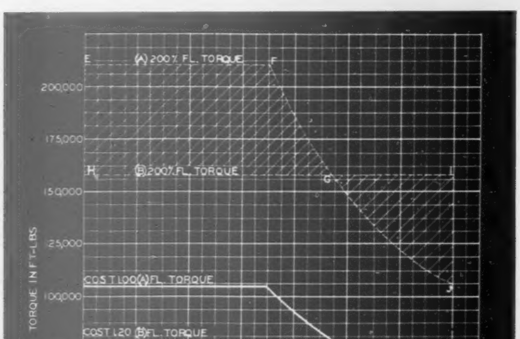


Fig. 1

Referring to Fig. 3, the speed torque curve of a 2:1 motor which delivers a full load torque of 41300 ft-lb at 850 rpm is given by curve XYZ and its cost is taken as unity.

The speed torque curve of a motor with the same hp rating but 850 rpm base speed is given by curves SZ and its price is approximately 80% of the first motor.

VW shows the curve of a motor with an intermediate value of maximum available torque, the cost of which is 2% more than the first motor.

Motor operation at full field is better from the standpoint of commutation and stability as compared to operation at ½ field strength or less, and consequently speed regulation in general is better since only a small range of main pole flux has to be dealt with.

For the smaller size drives full advantage of the Ward-Leonard System may be taken wherever suitable generating capacity may be assigned individually to the drive and the load requires constant torque; however, in the heavier drives practical design limitations affect the problem as well as load conditions.

Consider as an example a 3500 hp, 175/350 rpm d-c motor such as is used in steel mills for main drives. The solid curve (A) Fig. 1 is the full load speed torque curve of such a motor. Since such machines are rated at 100% overload for one minute, the available maximum rated torque is given in dotted curve (A) (EFGJ) for this motor. Such motors are controlled in speed by varying the generator voltage with full motor field from zero to base speed and at higher speeds by varying the field current.

Since $T = \Phi I K$ Where T = Torque in ft-lb
Φ = Field flux
I = Armature amp
K = Constant

and the current rating is constant for the given motor rating the torque at 175 rpm and full load current is twice that at 350 rpm and the torque at

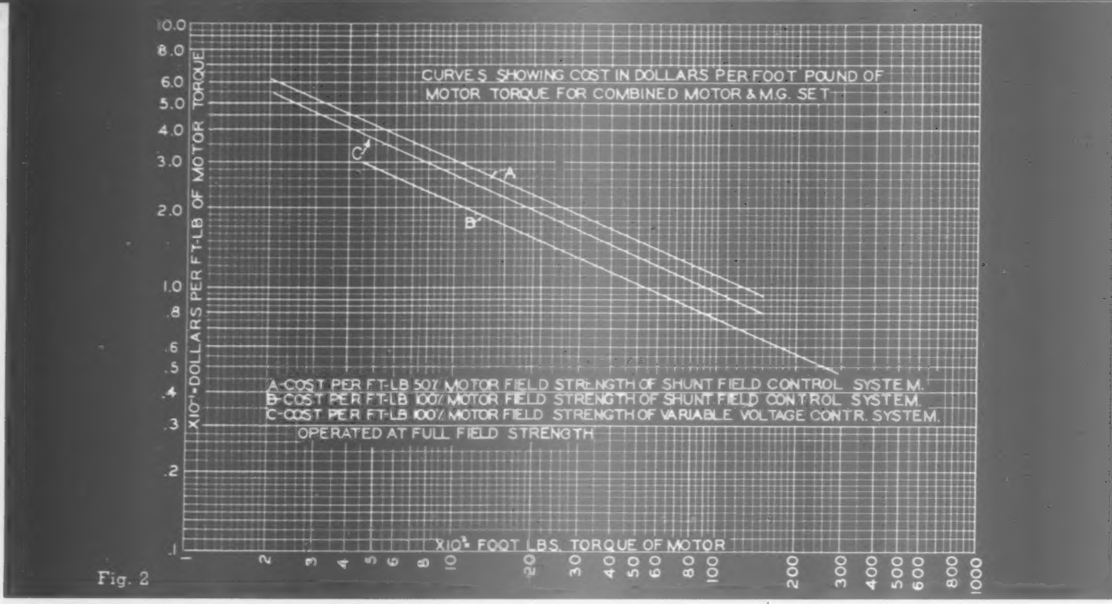


Fig. 2

100% overload at 350 rpm is the same as that at full load below 175 rpm or 105000 ft-lb. The same motor frame size with variable voltage control operating with full field from zero to 350 rpm, however, would give 105000 ft-lb from zero to 350 rpm and twice this at 100% overload.

However, since

$$hp = \frac{\text{torque x rpm}}{5250}$$

the rating of this motor would be

$$hp = \frac{105000 \times 350}{5250} = 7000 \text{ hp}$$

thus requiring a generator of twice the kw rating, as that required for the 3500 hp, 175/350 rpm motor. This motor, however, is not practical to build in a single armature.

A motor even at 3500 hp, 350 rpm base speed is not practicable to build under present practice with available materials due to excessive volts per commutator bar and other reasons. Within usual practice, Table I gives hp and full field speed limits.

TABLE I*

hp	Base Motor Speed with Variable Voltage Control Only	Base Motor Speed with 2:1 Field Weakening Control
250 to 500	1150 rpm	690 rpm
600 to 1000	850 rpm	575 rpm
1250	575 rpm	400 rpm
1500	500 rpm	350 rpm
2000	400 rpm	300 rpm
2500	350 rpm	225 rpm
3000	300 rpm	200 rpm
3500	250 rpm	175 rpm
4000	225 rpm	150 rpm

*Speed limitation in first column electrical. Speed limitation in second column mechanical.

To obtain then 3500 hp (52500 ft-lb) torque at 350 rpm, a twin armature machine (2-1750 hp) may be used with Ward-Leonard control without field weakening. The excessive available torque, however, below 350 rpm which reaches double value at 175 rpm as obtained with a 2:1 motor would be lost.

Taking the price of a 3500 hp, 175/350 rpm motor as unity, the price of the double armature machine would be approximately .90.

If only a moderate amount of added torque at low speeds is essential then a single armature machine 3500 hp, 262/350 rpm with speed torque curve KLM giving 70000 ft-lb torque at zero to 262 rpm may be used. The cost ratio of this machine compared as above is also .90.

However, if the load requires a constant torque drive since the 3500 hp, 175/350 rpm has only 52500 ft-lb torque at 350 rpm and 105000 ft-lb torque at 175 rpm let us apply a motor giving an intermediate torque (78750 ft-lb) from zero to 350 rpm. Such a machine would have a rating of 5250 hp at 350 rpm and would be a twin armature machine. Its cost ratio compared as above would be 1.20. The torque of this machine for full load armature current is given by solid curve B, Fig. 1, and the 100% overload or maximum available torque is given by dotted curve

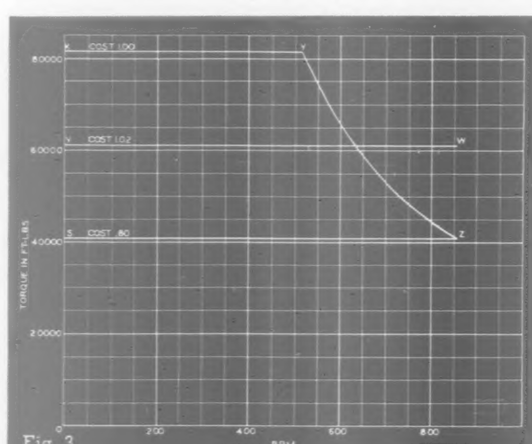


Fig. 3

B 200%. We then have 50% more torque available at 350 rpm and 75% of the torque of the 3500 hp, 175/350 rpm motor available below 175 rpm. The torque gained is represented by the area G, I, J and the available torque lost is represented by the area E, F, G, H.

For a constant torque drive, this extra available torque at high speeds is an advantage, however, where excessive torque is required occasionally at low speeds the motor giving curve A is the best and more economical, where field weakening is used as against full Ward-Leonard.

For smaller drives, however, the above design limitations given are not present. As an example, for 650 hp at 850 rpm having torque curve SZ, Fig. 3, with variable voltage control using the cost of this motor as unity, a similar motor 425/850 rpm with field weakening would have a cost ratio of 1.25 and its torque is represented by curve X, Y, Z, Fig. 2.

Similarly a motor with torque midway between the available torques for the two (above motors) at zero to 850 rpm has a cost ratio of 1.30 and torque curve VW.

The control equipment is practically the same for either case where single motor drives are involved. However, in a continuous process where a number of motors are required invariably individual speed adjustment is required between motors. If all motors are supplied from a single generator it is necessary to have shunt field control for this adjustment of speeds.

Also if more than one generator and motor is required it is very advantageous to operate them in parallel as the overload requirements will then be distributed between generators and the resultant overall speed regulation will be better than if a generator is used for each motor with variable voltage control without field weakening.

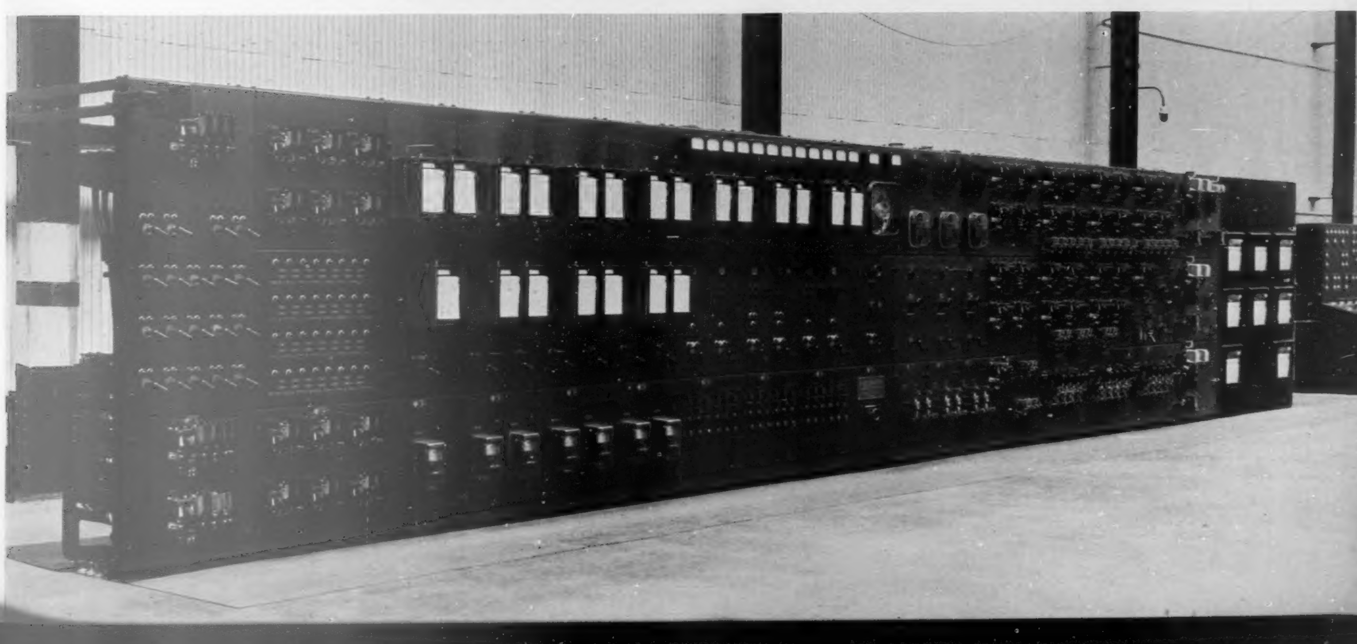
Where a generator is used with Ward-Leonard control for each motor without field weakening in such a process the same overload capacity must be supplied in the generator as in the motor and moreover the speed regulation and the regulation of relative motor speeds becomes a special control problem. With widely fluctuating loads the problem of keeping each motor speed proportional to the speed of the other motors requires very accurate and sensitive regulating equipment. Furthermore, with suddenly applied loads, the impact drop is more than with parallel generators.

Considering the factors the scheme of using parallel generators with 2:1 speed range motors is the better for a continuous process where the load torque may vary with different products and individual motor speed adjustment is required. This is particularly true if very heavy torques are required occasionally.

The curves of Fig. 2 indicate that if a motor with field weakening is used only at the high speed, a variable voltage system with fixed motor field which would give the same torque would cost 15% less. However, if occasionally products have to be made requiring torque values greater than the 50% field value, then the combined equipment price will be about 15% greater than for such a variable voltage system. In other words, a field weakening system giving 200% of maximum speed torque available up to one half of top speed will, in general, cost only 15% more than a variable voltage constant torque system.

The difference between curves A and C shows the savings effected by using a variable voltage system for a given maximum speed without field weakening as compared to 2:1 speed control by field weakening. Curve B shows the cost per ft-lb at half speed and below of the 2:1 motor.

Variable Voltage D-C Control Equipment for Hot Strip Finishing Mill



A UNIQUE APPLICATION OF MERCURY ARC RECTIFIERS

• O. Keller
RECTIFIER DIVISION . . . ALLIS-CHALMERS MFG. CO.

One of the best examples of the versatility and unique characteristics of the mercury arc power rectifier is its use in a high capacity d-c circuit breaker short-circuit test plant.

The mercury arc rectifier is particularly well adapted for such an application because of the absence of electrical inertia and its utter insensitivity to short-circuits. The electric arc, which is the rectifying agent in a mercury arc rectifier, possesses no inertia, as the current is carried by electro-ionic conduction. In fact practically the only inertia possessed by mercury arc rectifier plants is contained in the transformers, and in this particular installation the inductance is reduced to almost nothing by eliminating the transformer and connecting the rectifier directly to an alternating-current generator of the test plant. Thus, there is no intermediate transformation of energy from the electrical to the magnetic form, and back to the electrical form, and the generator current is led directly to the test object, through the rectifier arc, without undergoing any intermediate transformations. The connections are so arranged that the rectifier can be operated either as a 3-phase, a 6-phase, or as a double 6-phase unit. The installation is shown on the opposite page, where the rectifier is in the immediate foreground with a small air circuit breaker mounted on the test panel shown to the left of the rectifier.

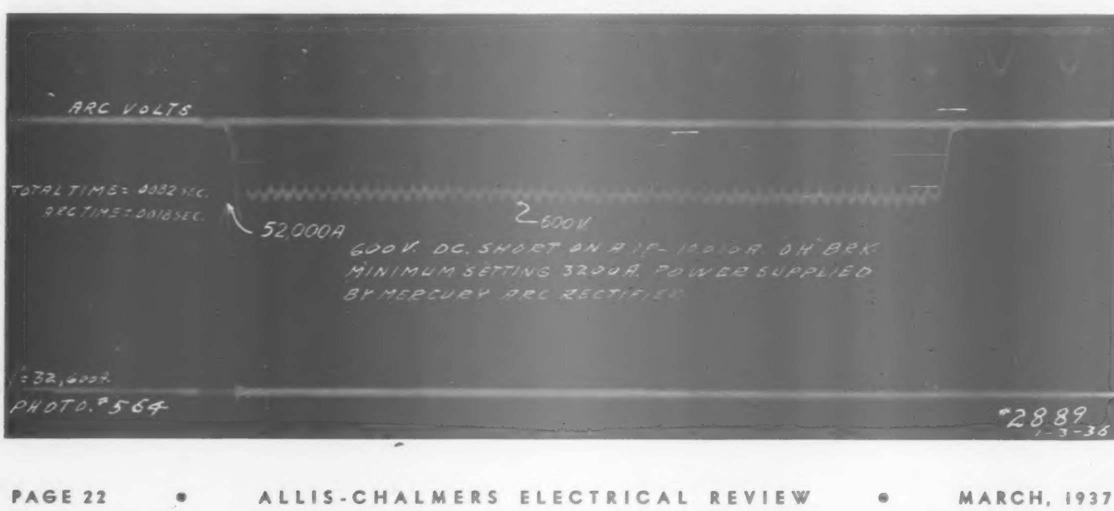
Since the rectifier is capable of delivering up to 750 volts at 15000 to 20000 amp for short intervals, and peak loads of two or three times that figure, and since it has, as mentioned above, only negligible inductance, it is an ideal source of testing current for this type of breaker.

This plant is constantly being used, and has been found to be extremely useful in the development and testing of high-speed and high-current breakers of various types.

The rectifier is equipped with the usual evacuating and vacuum measuring equipment, as well as with standard ignition and excitation auxiliaries. If it has been standing idle for some time between tests, it is desirable to form it by operating it at a light load of several hundred amperes, at a low voltage, for a number of hours before a short-circuit test. Under some conditions it is also helpful to have the rectifier supplying a small base load during a test.

The oscillogram on page 22 shows the performance of a high-speed air circuit breaker when tested

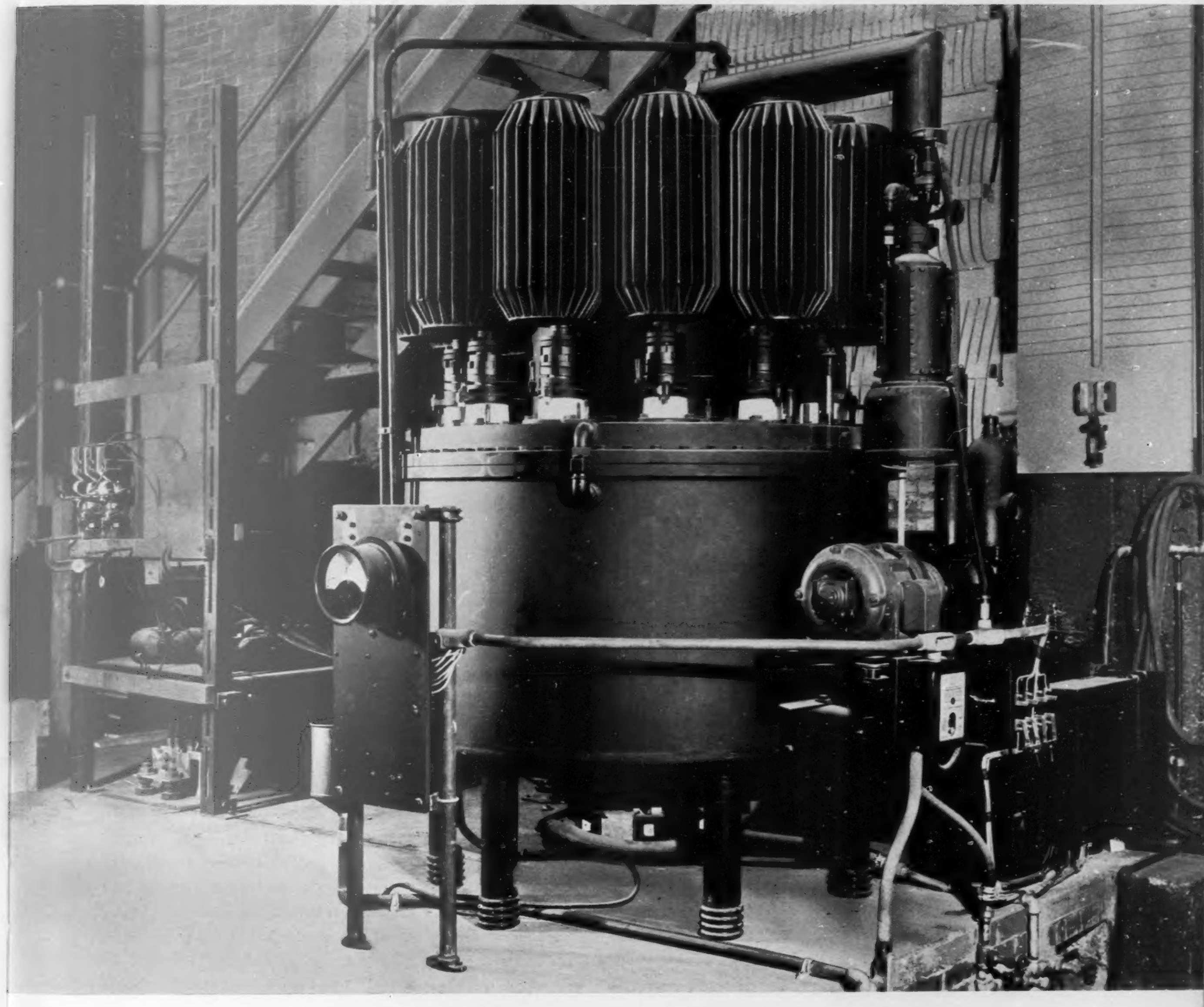
Oscillogram Shows Performance of a High Speed Air Circuit Breaker when Tested with the Rectifier



in conjunction with the rectifier. The short-circuit current shown in the oscillogram was rising at a rate of approximately 9,000,000 amp per second, which is almost as fast as the rate of rise possible in any present-day commercial direct current circuit. In this case the current rose to 52000 amp in 0.0063 seconds (0.38 cycles), showing that since the commutating action of a mercury arc rectifier takes place in a very high vacuum, no injurious effects are caused by current surges of such magnitudes. It will be noted from the oscillogram that the total interval during which the short-circuit current was carried by the rectifier was 0.0082 seconds (0.49 cycles). The minimum setting of the breaker for this test was 3200 amp.

Such a rectifier installation is probably the simplest and least expensive source of short-circuit currents of such magnitudes which may be made available at frequent intervals and in quick succession.

RECTIFIER FOR CIRCUIT BREAKER TESTING



THE SPEED-GRAPH

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CONDIT WORKS . . . ALLIS-CHALMERS MFG. CO.

To properly check the adjustment of an oil circuit breaker it is necessary to obtain records of its operating speed on both closing and opening strokes.

On the smaller breakers a record of overall time, such as may be obtained with a cycle counter is usually adequate; but on the larger breakers where there are several factors involved in adjustment more information is required. To properly and readily check the adjustment of the trip-free mechanisms, accelerating springs and shock absorbers a direct-acting and direct-reading curve drawing instrument is necessary. The speed-graph is such an instrument.

For many years, the cycle-counter was the only instrument readily available for routine checking. Cycle-count checks were supplemented by magnetic oscillograph records for design purposes, but the complications of oscillograph set-up and slide wire adjustment and calibration practically prohibited its use for routine or field work and made design tests arduous and subject to the delays and difficulties of interpretation of oscillograph records.

The cycle-counter can only be used for point to point timing and is not accurate within a cycle or more. Various other devices have been used for point to point timing, one of which consisted essentially of a telegraph sounder operated by a-c current and arranged to punch holes in a paper tape. This device has an accuracy of ½ cycle. An early curve drawing instrument employed a mechanically driven stylus to draw a track on a piece of smoked glass. Various other devices have been used, most of which were subject to inaccuracies due to non-uniform scales or lost motion.

With the development of modern breakers with the more accurate adjustments necessary to meet the requirements of high operating speeds, the development of a simple, yet accurate curve drawing device became almost imperative and the speed-graph meets these requirements. Figure 1 shows a general view of the instrument. It consists essentially of a vertical drum carrying a ruled chart, driven by a synchronous motor through a suitable gear reduction; and a pencil operated either directly or through reduction means from the lift rod or cross head of the breaker. Additional pencils are provided, magnetically operated, which record on the same chart and in the proper time relation any other operations desired, such as the energizing of the trip or closing coil.

The chart drum is so arranged that, using the normal gear train the time calibration is exactly one inch per cycle. On breakers having 18 inch stroke or less a direct pencil drive is used so that travel is direct reading that is 1 inch equals 1 inch. For longer stroke breakers a 2 to 1 ratio pencil drive is provided.

The ruled chart which can be seen in Fig. 1 is wrapped around the chart drum with the start of the chart at an index point on the drum. The travel pencil is coupled to the moving member of the breaker and the necessary magnetic pencils connected. The synchronous chart motor is then started. Then the desired breaker operation is initiated from the control handle. A record synchronizing switch provided on the drum of the speed-graph automatically times the breaker operation so that the record will be taken in the correct location on the chart.

Spaces are provided on the ruled chart for recording breaker identification and adjustment records. The record is thus made complete on the job and may be witnessed if desired, and contact print reproductions made immediately.

Figures 3 and 4 show typical closing and tripping curves respectively on a large outdoor breaker. These speed-graph records indicate the actual breaker speed at every point in the stroke and the time from the initiation of the operation to any point in the stroke all clearly and accurately shown without the necessity for calibration or interpolation.

Speed-graph records may be made on any breaker, large or small, with or without oil. When tests on indoor or frame mounted breakers without oil are required, it is usually convenient to remove the tank and connect the travel pencil to the movable member of the breaker. On floor mounted breakers, or where tests are required with oil in the breaker, the device is located on top of the breaker

Fig. 2 — The Speed-graph in Test Position on a 138 kv Oil Circuit Breaker.

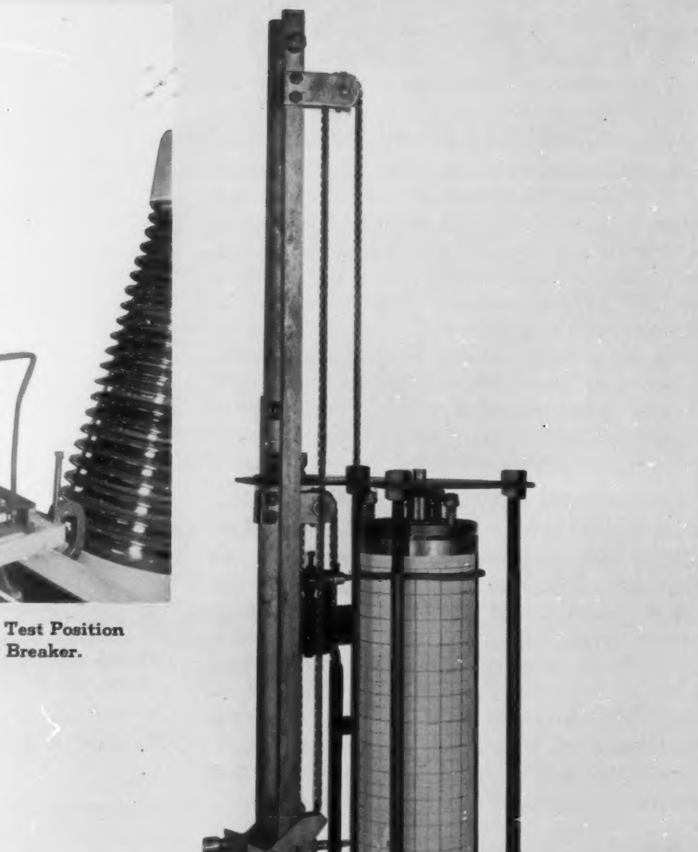

Fig. 1 — The Speed-graph.

and connection made to the fitting on the top end of the lift rod. Figure 2 shows the speed-graph mounted on a 138 kv outdoor breaker. On breakers not having a removable cover over the mechanism well, a removable plug is provided to permit making the necessary connection to the breaker lift rod.

To those closely associated with modern breaker design and adjustment the value of the speed-graph is apparent. Most modern breakers are in the so-called 8 cycle or high speed class. That is they must interrupt any overload or short circuit between 25 and 100% of their interrupting rating within 8 cycles (.133 second) measured from the instant that the breaker trip coil is energized. Modern high-speed breakers must have efficient interrupting devices but they must also have mechanical speed, and mechanical speed means co-ordinated parts and co-ordinated adjustments, or, in other words, balance.

In the design of a new breaker, this co-ordination is no inconsiderable task. From the interrupting tests on similar breakers the maximum arc length and arcing time can be predicted closely. The problem is to trip the breaker latch, accelerate the moving parts and get the prescribed contact separation within the given time, usually 8 cycles. A preliminary design is made, set up and speed-graph records similar to those shown in Figs. 3 and 4 are made. These charts give an accurate curve record of what happened during the breaker operation—the time from energizing of the trip coil to initial movement of the contacts, to contact separation, to the necessary contact separation for arc extinction; the time at which the accelerating springs disengage and the decelerating means engages; the speed at any and all points in the opening stroke; and the rate of acceleration and deceleration.

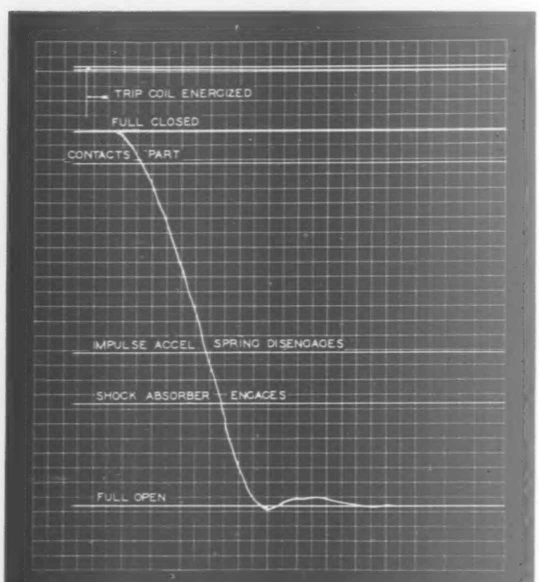

Fig. 3—Speed-graph Record of Tripping Operation on 138 kv Oil Circuit Breaker

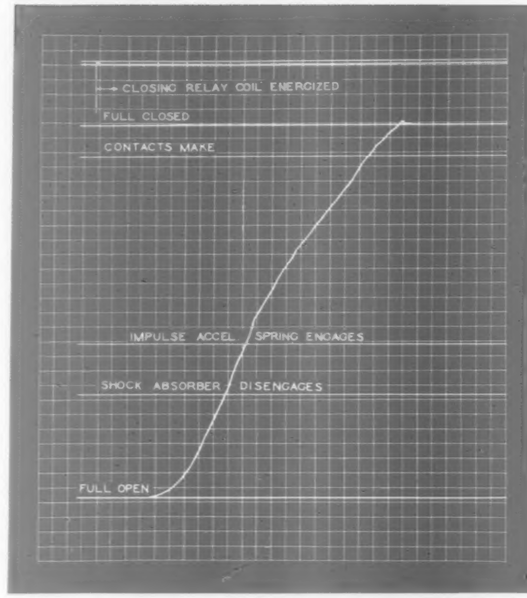

Fig. 4—Speed-graph Record of Closing Operation on 138 kv Oil Circuit Breaker

Is the mechanism slow in releasing? Is the initial acceleration too slow? Does the accelerating means work through a sufficient portion of the stroke or does the acceleration drop off too soon? Is the decelerating means adequate to prevent rebound or undue shock? All these questions are answered directly by the one record. Changes in adjustment or arrangement may be made immediately and the resulting change in the opening characteristics noted.

The closing—or reclosing operation—can be studied in a similar manner. Is the pick-up on closing sluggish? Is the final speed so great as to cause undue mechanical shock? Is the reversal of motion on high speed reclosing duty smooth? Does it take place sufficiently near the end of the stroke? Is undue time lost on the second trip-out because of residual magnetism? All of these questions can be answered and any discrepancies corrected readily and quickly by the use of the speed-graph.

Similarly on the routine adjustment checks of production breakers in the factory and on adjustments in the field, the speed-graph gets the story quickly, easily, and directly in a form readily understood, even by those less familiar with the circuit breaker art.

INDUCTION VERSUS SYNCHRONOUS MOTORS

• G. Byberg
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While numerous articles have been written on the subject of power factor correction and much emphasis placed on the desirability of maintaining high system power factors, we believe that further discussion of related subjects may not be entirely inopportune. There is no intention here whatsoever to question the virtue of sustaining the effort of attaining better system power factors; the facts causing the effort are all too obvious to be open to question.

Low power factors and the concomitant lagging reactive currents increase generator, transformer, transmission line and feeder copper losses, limit the "true power" carrying capacity, and have a disturbing influence on the voltage regulation of these links of the system. The central station, therefore, is perfectly justified in imposing penalties for low power factor, since such loads tend to restrict the output of the generating and distributing system, and also result in operation at lowered efficiencies.

As has been so many times mentioned, the chief means by which system power factors have been improved is the increasing use of synchronous motors, operating at unity, or leading power factors and compensating for the lagging magnetizing current drawn by induction machines. The synchronous motor incidentally performs another very useful function, namely: acting as an aid to maintaining voltage regulation, and with a number of synchronous motors on a system, this function augments other voltage regulating equipment to no inconsiderable extent. From the line and distribution system standpoint, the only objection that can be offered to a great number of synchronous motors on the system is that they tend to increase the short-circuit currents flowing into a fault, but with present-day switching protection this has not been found troublesome.

Synchronous condensers are in many cases also installed at the load centers having low power factors for the sole purpose of correcting for those particular loads. The larger condensers are installed on the transmission line, or at distribution centers for the dual purpose of power factor correction and voltage regulation; usually, under automatic control designed to operate the condenser over its range to compensate for power factor and voltage changes with varying loads.

The commendable increase in the use of the synchronous motor is a tribute to the user, who, with little hesitancy, accepted it throughout the earlier years of its development, as well as to the unremitting work of the designing engineers, who successfully solved the multiplicity of design problems and carried the motor through to its present day reliability and adaptability.

However, it appears at times as though the eminent success attained in synchronous motor design, coupled with the always present problem of power factor correction, may have caused an excess of fervor for its application. And, we would like to draw attention to the fact that even in view of the foregoing, the squirrel cage, or wound rotor induction motors of the sizes above the general purpose ratings (general purpose ratings are ratings up to 200 hp) are not by any means outmoded and ready to be relegated to the limbo of past usefulness.

There are, of course, many applications in the larger sizes where the synchronous motor is the only logical choice; e.g., most centrifugal pumps, fans and blowers, air, freon and ammonia compressors of the low speed reciprocating type, motor generator sets, Banbury Mixers in rubber mills, Jordan engines and pulp grinders in the paper mills, ball or tube grinding mills in the cement and mining industries, and a number of others utilizing low speed, direct connected drives.

There are also industries where there will be only a relatively few large motors for drives to which the synchronous motor is applicable, and these must then be utilized for that purpose, since, ordinarily it will be cheaper to purchase the corrective leading kva in a few large motors than in numerous small ones, as in the case of a saw mill where the band saw, chipper, and possibly a compressor are usually the only drives in the mill requiring large motors.

But conversely it would seem preferable to apply the induction motor to certain drives where there has been considerable tendency to use the synchronous motor, even though the latter may not

be as practicable for the particular purpose as the induction type. It would seem preferable, for instance, to use the wound rotor induction motor for crushers, or for a pulp beater; the double squirrel cage motor for a coal pulverizer; and the normal torque low starting current squirrel cage motor for pumps, blowers and compressor drives at very high speeds, and of horse power limits as mentioned later.

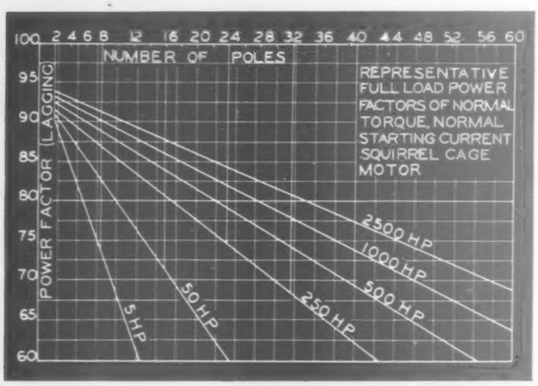


Fig. 1

• The induction motor power factor

Many prospective users of large motors are prone to dismiss all except the high speed induction motor from consideration under the impression that its power factor is uniformly low. This impression often may be held where the purchaser's experience has been largely limited to the smaller sizes of low speed motors and his judgment is based on the power factor characteristics of those smaller machines.

In Fig. 1 are shown characteristic full load power factors of normal torque, normal starting current, squirrel cage motors (NEMA Class A) of various ratings from 5 to 2500 hp, of 2 to 60 poles, and for standard voltages of 440, or 550 for the smaller, or 2200 volts for the larger sizes (2 pole corresponds to 3600 rpm, 60 cycle, or 1500 rpm, 25 cycle; 24 pole would correspond to 300 rpm, 60 cycle, or 200 rpm, 40 cycle). These values have been plotted by poles as abscissae against power factors as ordinates, and in straight lines which is not strictly true but sufficiently accurate for this purpose. Actually, the intermediate ratings will have somewhat better power factors than shown for the range of 6 to 14 poles.

From these curves it will be seen that the power factor is dependent on two things, namely: the number of poles and the horse power rating. Hence, the number of poles, or speed alone, does not form the criterion for power factor.

For given horse power ratings, the power factor decreases inversely with the number of poles, since the magnetizing current will increase almost in direct proportion to the number of poles.

The reason that the large horse power motors have much better power factors than the smaller ones is that as the physical dimensions of the active parts of the motor increase, the "output factor" increases, due to the possibility of better utilizing the active materials.

The term "output factor" equals

$$\frac{\text{hp (or kva) output}}{D^2 \times L \times \text{rpm}}$$

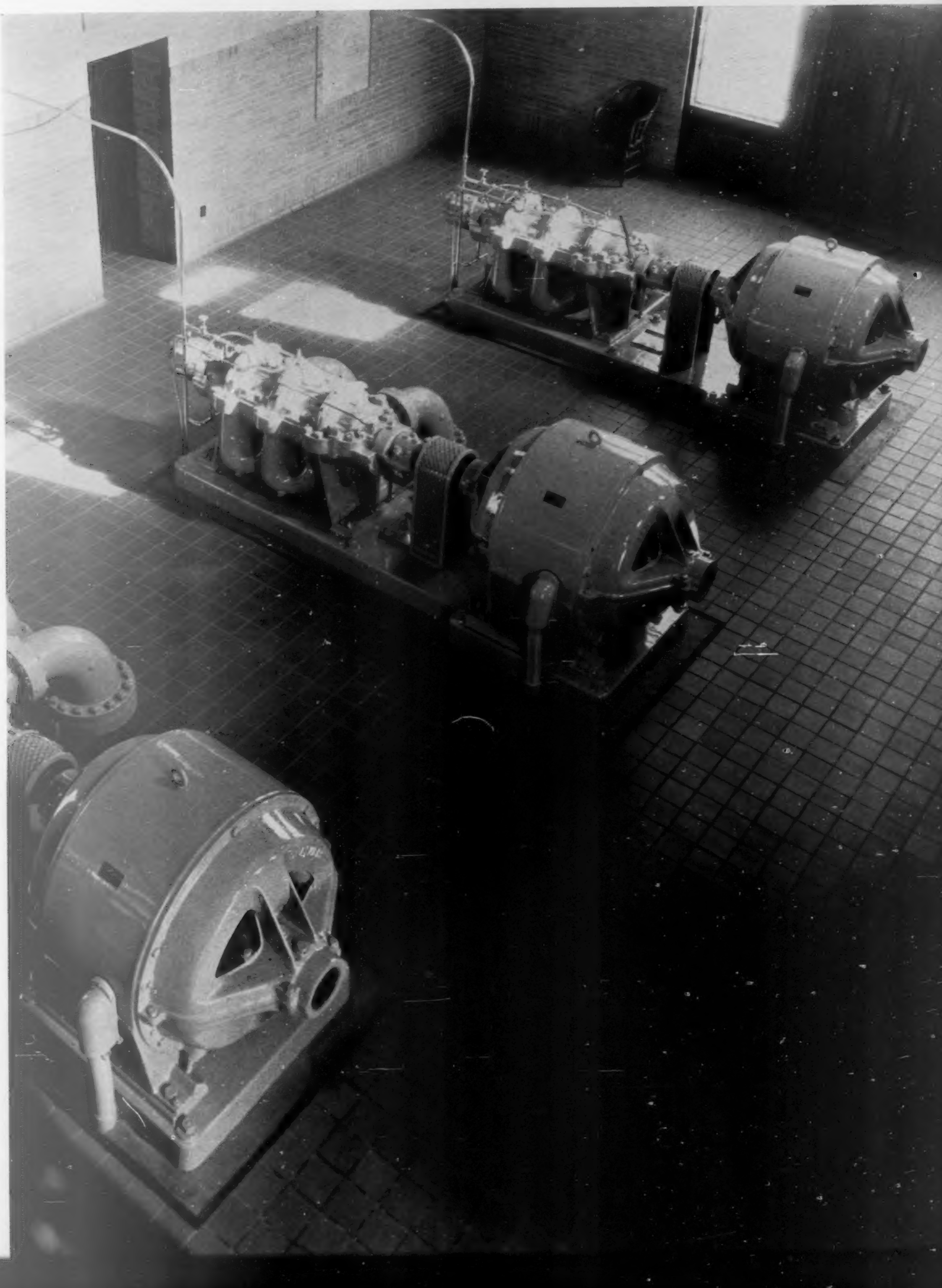
where D is the outside rotor core diameter and L is the active length of the core. This output factor is primarily the function of two design factors and increases with the frame diameter and the pole pitch. Thus, with increasingly larger ratings, the amount of core iron and consequently, the magnetizing current required becomes less per horse power output and the power factor improves.

Hence, in the interest of the best possible power factors, it is desirable to build induction motors on the largest economically practicable diameters. There are, however, reasons why limits must be placed in following this tendency, of which the following are the most obvious ones:

1. In order to make the motor cost reasonable, a certain ratio must be maintained between the active and the inactive parts. By active parts is meant those parts forming the magnetic and electric circuits, such as the armature and rotor core, the armature and rotor coils. By inactive parts are meant the stator yoke, rotor spider, shaft, base and bearings.
2. In very large, high speed motors, the diameter may be limited by the peripheral rotor velocities and centrifugal stresses on the component parts of the rotating element.
3. In large low speed motors while the diameter automatically becomes larger, space limitations may not permit the installation of induction motor of still larger diameter, which has the most desirable characteristics.
4. Manufacturers have developed standard lines. The cost of developing a special motor having the most ideal characteristics for each individual case is prohibitive.

It is evident from Fig. 1 that while it would be poor engineering (from a power factor standpoint) to install a 50 hp, 24 pole motor (300 rpm, 60 cycle) it may be worth considering in the case of a 500 hp motor and would not be at all bad for a 1000 hp rating. This, of course, on the assumption that existing load power factor is fairly good, that the torque characteristics of the induction motor are better

INDUCTION MOTORS DRIVING PUMPS



suited to the particular service, and conditions of installation are such that an induction motor is more readily protected against unfavorable conditions. What we wish to bring out here is that when we get below the high speed class (500 rpm), the size of the motor has a great deal to do with its suitability.

In using the curves of Fig. 1, several things must be remembered:

1. It is based on full load conditions, and if the motor is to be applied to a varying load drive, the fractional load power factor must be considered.
2. It is based on normal torque, normal starting current motors and other types, such as normal torque low starting current (NEMA Class B), or a high torque low starting current (NEMA Class C), double cage motors and wound rotor motors will have slightly different characteristics.

• Fractional load power factor

In Fig. 2 are shown the fractional load power factor characteristics of high and low speed cage motors. From these curves it will be evident that the higher the full load power factor the better will be the fractional load power factor, and vice versa. A rough rule is that the half load power factor will be slightly better than the square of the full load power factor; i.e.: If the full load power factor is 94%, the half load power factor will be $.94^2$, or 88%, or, if the full load power factor is 70%, the half load will be $.70^2$, or 49%, or a little better. For this reason it is advisable to confine lower speed induction motors to drives where the load is constant at, or near, full load.

The three quarter load power factor will approach the full load power factor for high speed motors, but will be from 3% to 6% lower with the low speeds.

• Other types of induction motors

Class B motors have inherently higher reactance than Class A, and, therefore, power factors will be somewhat lower than shown in Fig. 1 for the latter type. The amount by which it is lower will vary from 1% for high speed motors to 2% or 3% for low speed motors at full load.

Class C motors (double cage) will have power factors of from 3% to 5% lower for high speed, and from 5% to 7% lower for low speed motors at full load.

Wound rotor motors will have power factors varying from 1% lower in the high speed class, to 5% lower for the low speeds.

• Synchronous motors at fractional loads

In order to show the opposite action on power factor at fractional loads, the power factors of synchronous motors for fractional loads have also been plotted on Fig. 2, both for motors rated 100% and 80% leading power factor at full load. The fractional load power factors are based on the field excitation remaining constant at the full load setting. As the load decreases, the power factor lead increases; 100% power factor motors draw some leading reactive kva from the line and leading power factor motors, while drawing less total kva from the line, do so at a greater leading power factor, so that the reactive kva remains nearly as high as at full load. The net result is that almost exactly the same system load power factor is maintained, while the total load kva is reduced.

Hence, unavoidable fractional load conditions rather than being detrimental, as in the case of the low speed induction motors actually may prove to be beneficial. This is not intended to mean that oversize motors are recommended, since efficiencies will

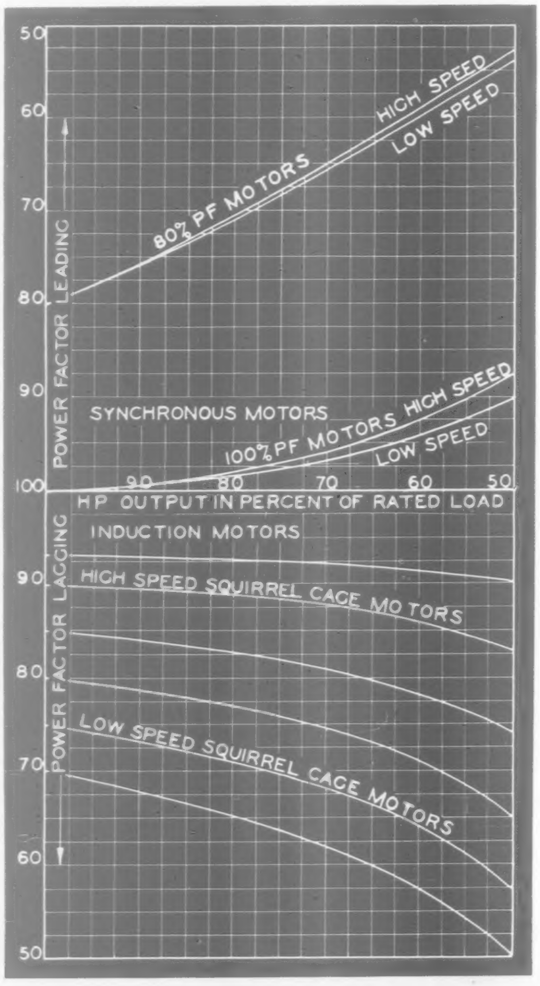


Fig. 2

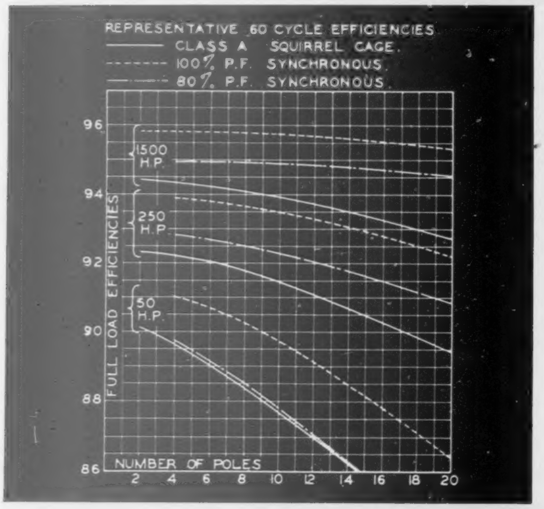


Fig. 3

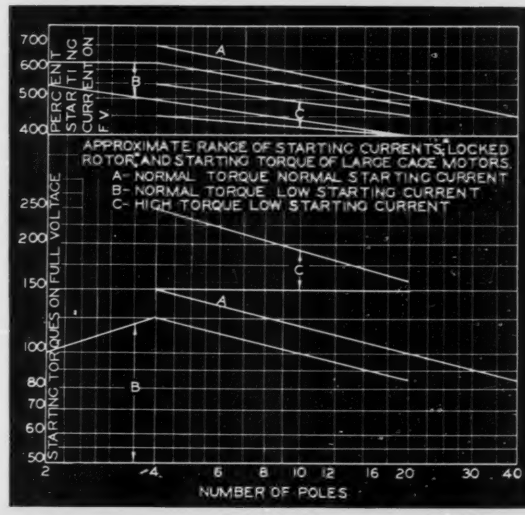


Fig. 4

be lower at fractional loads. It is more economical to purchase a synchronous motor of the required horse power, and at such leading power factor as will give the required leading reactive kva, rather than attempt to obtain that required kva from an oversize unity power factor motor. One reason for that is that a unity power factor motor is, in order to obtain higher efficiency, not designed to permit over-excitation of the field.

• Efficiencies

Some comparative full load efficiencies of high speed induction and synchronous motors are shown by Fig. 3. The efficiencies shown include losses in accordance with the latest A.I.E.E. Standards (C-50 of 1936). From this figure, it will be evident that unity power factor synchronous motors show better efficiencies than Class A squirrel cage motors, of corresponding ratings, but decreasingly so the higher the speeds.

The 80% leading power factor synchronous motors will have slightly lower efficiencies than the Class A squirrel cage in the smaller sizes, but will be somewhat better in the larger sizes.

Class B motors having torques in the lower range shown by Fig. 4 will have efficiencies comparable with Class A. Class B motors within the higher range of torque values will have efficiencies from ½% to 1% lower than the Class A squirrel cage motors.

Class C squirrel cage motors will have efficiencies approximately 1% lower than the Class A cage motors.

Wound rotor motors will have approximately the same, or, in some cases, slightly better efficiencies than the Class A cage motors.

The efficiencies for induction motors of more than 20 poles will not decrease quite as rapidly as indicated, the curves having a tendency to flatten out beyond 16 poles more than the curves show. For example: a 250 hp motor at 240 rpm will have a full load efficiency of 89½%; a 1000 hp motor at 150 rpm, a full load efficiency of 91%.

• Induction motor torques and starting kva

Figure 4 is indicative of the range of starting torques and starting kva of the three commonly used classes of squirrel cage induction motors.

One of the most important things to remember in connection with the standard cage motor is the fact that any change in only one characteristic affects practically all other characteristics of that motor.

Using a Class A motor as a basis of comparison, then for a motor requiring a higher starting torque, this means a motor of lower efficiencies, slightly reduced starting current, a slight increase in the power factor, greater slip, and lower maximum torque, etc.

Specifying a lower starting current than normal, means lower starting torque, lower power factor, and lower maximum torques, etc.

Lower starting current and higher starting torques, or lower starting current and higher maximum torques; or, higher starting current and higher efficiencies are practically opposites. Thus, it should be fairly obvious that if any one characteristic is essential, it must be obtained at the expense of a number of other characteristics. You cannot have low starting current and a high starting torque, or you cannot have low starting current and large maximum torque; but you can have a reasonably low starting current with low starting torque and high efficiency, or, similarly, a reasonable high starting current with a higher starting torque and efficiencies.

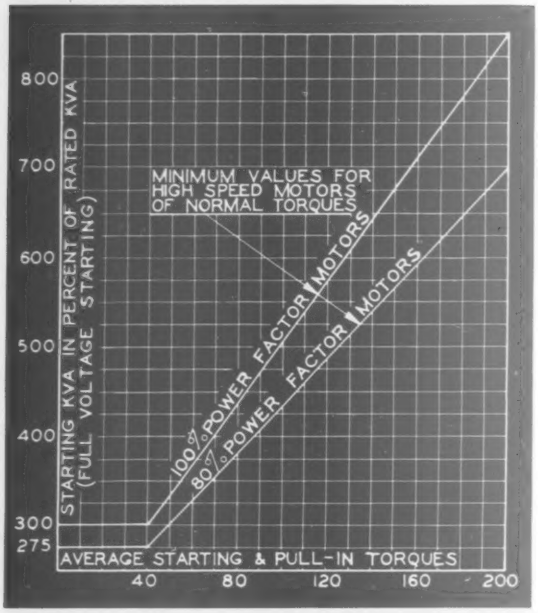


Fig. 5

The higher the starting torque, the lower will be the maximum torque, and conversely, the lower the starting torque, the higher the maximum torque will be.

The values of starting torque, shown by Curve A of Fig. 4, are those given by A. S. A. Rule 5.070 (050, 1936), and the corresponding starting currents are average values.

The values of starting torque and starting current given by Curve B for the Class B motors are probably of the greatest interest, since the practice of starting squirrel cage motors directly across full line voltage has become so common. Due to it, certain modifications of the standard squirrel cage construction are used principally for the purpose of reducing the inherently high starting current, and, also, to reduce starting torque values.

Naturally, a static torque equivalent to that of the Class A motor would be much higher than ordinarily would be required for the majority of applications. Therefore, advantage is taken of this to increase the efficiency of the motor at the expense of reduced starting torque. Hence, the starting torque limits of this class may vary from approximately 50% as the minimum requirement, and all the way up to 125% as the maximum requirement, depending upon the nature of the load, or driving machine. The low torques developed tend to reduce the mechanical shock to both the motor and driving machine, but obviously also lengthen the time of acceleration, although not to an objectionable extent.

The torque values for two pole motors have for this reason been purposely reduced to a range of from 50% to 100%, since with the class of drives there encountered no valid reason appears why higher torque values should be called for.

Starting torques of from 150% to 250% can be obtained with the Class C (double cage), as shown by Curve C, with starting currents ranging from 400% to 550%.

Neither the Class B nor the Class C are ordinarily built for more than 20 poles. The first class is built in ratings up to 2500 hp, and also exclusively for two pole motors. The latter class is seldom used above 500 hp for the reason that the type of drives to which it is applicable usually are seldom built of such size as to require ratings in excess of this value.

Figure 5 is indicative of average starting and pull-in torques of synchronous motors with corresponding values of starting kva. It is to be noted that this curve is based on starting and pull-in torque values being the same. This, for the purpose of simplification. Ordinarily, torque values are seldom required to be the same. Therefore, when the starting torque value is the higher of the two, the starting kva will decrease, and when the pull-in torque value is higher, it will increase. The extent to which the values will increase or decrease will depend to some extent upon the speed of the motor and also on the ratio between the starting and pull-in torques.

Figure 5 makes an interesting comparison with Fig. 4. If, for example, we take a 10 pole motor at 720 rpm, we find the following:

Type of Motor	Torques		Starting kva on Full Voltage
	Starting	Pull-In	
Class A Cage	120%		590%
Class B Cage	50 to 100%		440 to 545%
Class C Cage	150 to 190%		425 to 495%
Synchronous 1.0 pf	120%	120%	575%
Synchronous .8 pf	120%	120%	500%

• Two pole motors

Two pole motors require special mention as they are really in a class by themselves. The squirrel cage motor is built only in one class, namely: Class B. The Class A motor takes too high a starting current and develops much higher starting torques than required for the applicable drives, except, of course, when reduced voltage starting is used. The Class C motor develops far too high torques, and furthermore, the rotor structure does not really lend itself to double cage construction.

The smaller two pole synchronous motor is usually built with a distributed field type of rotor as against the salient pole type for motors of four or more poles. In the smaller sizes it has two objec-

tionable features, namely: high cost and extremely high starting kva. The rotor will require the same kind of forged steel rotor body, mica insulated field winding construction as the turbo-generator with special coil retaining end rings and slot wedges, designed also to perform the dual function of forming the squirrel cage starting winding. The starting kva will be on the order of 1000% of rated kva or higher when starting on full voltage.

In synchronous machines, the output factor reaches its maximum for a given rotor diameter with an 8 or 6 pole machine. From 6 poles it drops rapidly to the 4 pole, and from there still further to the 2 pole. This decreased output factor naturally means relatively larger physical dimensions, which, acting cumulatively with the more expensive construction necessary on account of high speed, results in a costly motor.

The reduction in output factor is due primarily to field heating and this, to some extent, also adversely affects the 4 pole motors.

The smaller 2 pole cage motor is not nearly so handicapped by this output factor limitation, since there is no exciting-field heating to contend with.

It has, therefore, a considerable advantage over the synchronous motor as far as cost is concerned, and this is clearly shown by Fig. 6. These curves show price comparisons between cage motors and unity power factor synchronous motors, having direct connected exciters, for various ratings from 250 to 2000 hp. This is based on Class B cage motors at 3600 rpm, and Class A cage motors for speeds of 1800 rpm and lower.

In connection with this cost comparison, it may be interesting to note that 80% leading power factor, two pole motors average 17% higher in cost than a 100% power factor motor of the same horse power rating.

The control cost has not been included in this comparison, as there is not a great deal of difference in cost between the synchronous and cage motor controls for a given type and rating, except that the addition of the field contactors and relays for the synchronous control increase its cost slightly.

In plotting these curves, the following torque values were used in establishing costs:

Rpm	Squirrel Cage Starting	Squirrel Cage Maximum	Synchronous Starting	Synchronous Pull-in	Synchronous Pull-Out Up to 500 hp	Synchronous Pull-Out Over 600 hp
3600	50-125	200	50	50-100	150	200
1800	150	200	110	110	150	200
1200	135	200	110	110	150	200
900	125	200	110	110	150	200
720	120	200	110	110	150	200
600	115	200	110	110	150	200
514	110	200	110	110	150	200

It should be evident, then, that unless the power factor problem is acute, it is questionable whether the two pole synchronous motors should be considered for ratings below 1000 hp; certainly not for ratings below 500 hp. It is recommended that where ratings of 500 to 1000 hp inclusive are involved, quotations be asked for on both the synchronous and the squirrel cage type, in order that the problem may be studied from both sides, and in conjunction with existing load conditions, to determine whether the higher cost of the synchronous motor is justified. And the same recommendation might very well be applied where four pole motors of ratings 250 hp and smaller are involved.

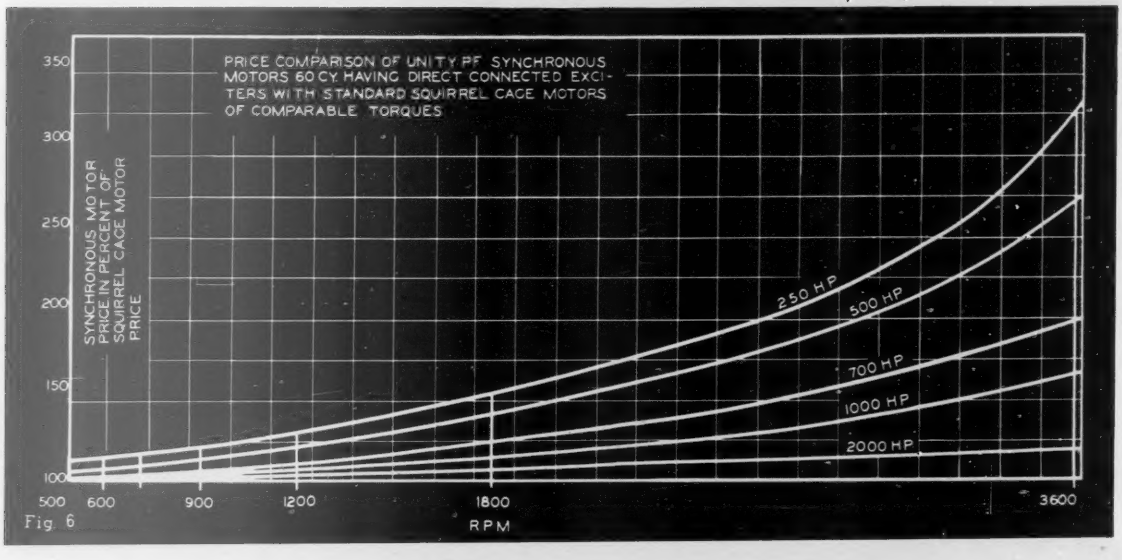


Fig. 6

For, it should be remembered, that the power factors of two and four pole cage motors are uniformly good for all ratings at fractional as well as at full load. Also, that adding a load at higher power factor to an existing load of low power factor also will improve the total load power factor as long as the motor power factor is greater than the load to which it is added.

It must be emphasized, however, that as the size increases, the disadvantages of the two pole synchronous motor diminish until a point is reached at about 1750 to 2000 hp, where the costs of the synchronous type become very favorable as compared to the squirrel type. And when we reach 3000 hp, the conditions reverse and the difficulties of constructing a laminated rotor for the cage type become exceedingly troublesome, its costs are increased exorbitantly and it is well to eliminate its consideration and resort to the synchronous type only.

Space does not permit going into the detail of every conceivable drive and explain why the synchronous motor is preferable in one case and an induction motor in another case. However, we have tried to indicate by the diagrams in this article the most important characteristics which form the basis for a comparison between the two types of motors.

SYNCHRONOUS MOTORS DRIVING PUMPS